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It was found through on-site investigations and questionnaires that local authorities were just starting to consider their I/I problems. Roots were found to be a major sewer system problem. Tide gates were found to be considered satisfactory, although generally they receive infrequent maintenance and often do not properly close.

The results of the study are presented in four volumes. This report reviews a sample economic analysis and information concerning root control and tide gates as determined by the study. The Appendices (EPA-600/2-77-017b) review the literature published to 1975, the field reports on root control practices, and experiences with the tide gates and backwater flow devices. The third report (EPA-600/2-77-017c) is a Product and Equipment Guide for I/I detection and control. Information is given and manufacturers listed for six classes: cleaning, internal inspection, rehabilitation, flow measurement, safety, and pipe. The fourth report (EPA-600/2-77-017d) is a Manual of Practice which covers the I/I investigation, sewer system cleaning and rehabilitation, and guides for new construction.

The study updates a similar effort conducted in 1970.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report delineates the economic analysis, root control, and backwater flow control aspects of infiltration/inflow control for the user community's ready reference. Together with the I/I Appendices (EPA-600/2-77-017b), Product and Equipment Guide (EPA-600/2-77-017c), and the Manual of Practice (EPA-600/2-77-017d) it represents a concerted effort to compile needed information for local authorities and consulting engineers on the control and elimination of infiltration/inflow flows to sanitary sewer systems.

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Municipal Environmental Research
 Laboratory

ABSTRACT

This study was conducted to identify and analyze present practices for determining and controlling infiltration and inflow (I/I) and investigate the role of roots and tide or backwater gates in the I/I problem.

It was found through on-site investigations and questionnaires that local authorities were just starting to consider their I/I problems. Roots were found to be a major sewer system problem. Tide gates were found to be considered satisfactory, although generally they receive infrequent maintenance and often do not properly close.

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SECTION I

INTRODUCTION, CONCLUSIONS, AND RECOMMENDATIONS

INTRODUCTION

This report and the accompanying Appendices, Product and Equipment Guide, and Manual of Practice represent a joint effort by the USEPA, the American Public Works Association (APWA), and industry representatives to compile needed information for local authorities and consulting engineers on the control and elimination of infiltration/inflow flows to sanitary sewer systems.

In 1970 an earlier study was sponsored by 39 local authorities and USEPA to prepare a report and Manual of Practice(1). In the intervening years, much has been learned. Federal recognition of the problem has resulted in extensive regulations and guidelines. The practices outlined in 1970 have been improved and simplified to make practical the analysis of conditions in large sewer systems.

The current study has also shown major upgrading of local authority specifications. The 1970 report suggested an infiltration allowance of 200 gal/in-diam/mi/day (0.18 m^3/cm-diam/km/day) as achievable without increased construction cost. This limit appears to be the generally accepted specification today.

With the increased attention to I/I conditions, manufacturers have provided joints and sewer pipe appurtenances capable of meeting very exacting infiltration standards. In addition, auxiliary equipment and products have been developed for flow measurement, sewer repair, and rehabilitation and sewer inspection.

Most important, however, has been the number of local authorities who have used the available techniques and have successfully, and often dramatically, reduced I/I flows in their system. At the start of this study, there was great concern for the value in terms of cost and time required to study the I/I conditions prior to the USEPA Construction Grants Program. In the past year, the value of such studies has become apparent and many local authorities have been able to make significant reductions in their flows in a cost effective manner, reducing the cost of construction and operation of wastewater treatment facilities and the maintenance of their sewer system.

CONCLUSIONS

Infiltration/Inflow

Many local authorities have utilized an I/I investigation to accomplish major flow reductions, thus allowing smaller wastewater treatment facilities and lower operational costs.

At the time of the APWA survey, few local authorities had completed I/I studies in accordance with USEPA guidelines.

The magnitude (time and cost required) and complexity of the I/I survey efforts for major systems requires improvement and development of better methods.

A lack of trained reviewers in many states and USEPA regions coupled with a lack of completed studies to act as benchmarks, appear to have severely delayed completion of many I/I studies. Recent USEPA actions appear to be correcting this situation.

Rehabilitation of sewer systems must be a continual program to maintain design levels of I/I. Generally this will require increased funding.

Major sources of infiltration were found to be pipe defects, manholes, service connections, and poor initial construction.

Major sources of inflow were found to be open manholes, roof leaders, illegal connections, catch basins, and yard and ground drains.

As a result of the surveys conducted correlations were not evident relating infiltration or inflow to climate, geographical region, or population.

Infiltration design allowances have been reduced in recent years. Pipe and joint manufacturers have responded with greatly improved materials allowing a wide choice of pipe systems to be used. To achieve the low levels of infiltration, 200 gal/in-diam/mi/day (0.18 m^3/cm-diam/km/day), competent inspection is required and rigid adherence to construction specifications is required.

It is seldom cost-effective to correct all points of infiltration and some types of inflow. Only major conditions should be corrected prior to determining the economics of rehabilitation versus transport-treatment.

Correction of inflow conditions will generally be dependent upon political support of community leadership.

Many sources of inflow are on private property. Many local authorities reported that they could pay for such correction work.

Many important factors for economic analysis must be specific to the site. Sample calculations as developed in this report may be used only as a guide.

The cost of water conservation devices, such as flow-reducing shower heads and lavatory fixtures, may be cost-effective when the entire system costs are considered.

Roots

A survey of local authorities to determine the extent and effect of tree roots in sewers revealed that:

a. roots are a major sewer maintenance problem;
b. roots in conjunction with grease and sand contribute to clogged sewers reducing flow characteristics;
c. conventional root control practices such as cutting appear to encourage regrowth;
d. chemical methods of control have been developed and are being used very successfully by many local authorities;
e. the efficiency of the chemical control methods has not yet been tested with all types of plants; and
f. root penetration is a major problem in house laterals where sewer depth is less and construction may not have been adequately inspected.

Tide Gates

A survey of tide and backwater gates revealed that:

a. few local authorities or manufacturers have attempted to improve the design of tide gates, other than by changes in materials;
b. malfunctions of gates are frequent and often lead to large amounts of unnecessary flow to the treatment facility. Units were reported to malfunction as often as 29 days per year and allow up to 100 mgd (263 m^3/min);
c. maintenance practices were generally reported as minimal, in part due to the inaccessible location of many such facilities;
d. sensing facilities to determine when units are closed or open have been installed by some authorities with success. Such systems must be carefully designed and adequately maintained or they will be of no value;
e. corrosion is a major problem with most facilities. Choice of materials must be carefully made. Changes in levels of pollutants in the receiving water may affect the type and extent of problems which will be encountered; and
f. many facilities were found to have been abandoned due to lack of resources for maintenance, poor initial design, and inaccessibility.

General

The Manual of Practice and Product and Equipment Guide developed by this study should be of assistance to local officials and consultants. However, the effect of USEPA guideline changes and rapid developments in the improvement of infiltration/inflow (I/I) evaluation must be considered by each user.

RECOMMENDATIONS

The benefits of several successful I/I control programs should be documented and published for the benefit of those consulting engineers and local authorities who have not had experience with studies.

Local authorities should be encouraged to establish ongoing sewer maintenance programs following sewer rehabilitation in order that the treatment facilities will not be overloaded.

Local authorities should conduct flow monitoring activities after rehabilitation in order to evaluate the effectiveness of correction activities.

Local authorities should conduct public information programs highlighting the need for elimination of inflow sources from private property. Where such connections were legally installed, the local authority should consider paying for all or part of the correction work required.

Many factors which may directly influence the economic analysis should be directly studied and quantified to improve economic projections. Such factors as the cost of street cave-ins, increased cleaning required, and sewer backups on private property are examples of areas which require quantification.

Local authorities should annually evaluate the cost-effectiveness of requiring water conservation devices for all new plumbing installations. Rapidly changing financial conditions for both wastewater treatment and drinking water may make it advantageous to require such devices.

Controlled testing and evaluation should be conducted of the two major sealants to better define the conditions under which both can best be used.

Controlled testing of Vaporooter should be conducted to determine its effectiveness as a root growth inhibitor with trees and shrubs found troublesome in northern climates.

As a part of any program for the upgrading of combined sewer overflow regulators, tide and backwater gates should be refurbished and a monitoring system installed to allow remote sensing of the position of its gate.

Construction of house laterals must receive the same degree of concern and inspection as other sewers.

SECTION II

THE STUDY

To provide for the reevaluation of conditions in the I/I field, the U.S. Environmental Protection Agency authorized APWA to undertake Grant 803151 as described in this section.

Objectives

The scope of the investigation was as follows:

Task 1 - Conduct a complete literature review covering the I/I field, including detection, sewer system evaluations, technological developments, maintenance programs, design and improved construction practices, and rehabilitation of defective sewer systems.

Task 2 - Conduct a general survey of new and existing materials, methods and mechanisms used for I/I detection, evaluation, rehabilitation, and construction processes and procedures.

Task 3 - Conduct in-depth field investigations, interviews, surveys and studies of policies, practices and performance in I/I control achieved by municipal and regional sewer system agencies, state regulatory agencies, consulting engineers and I/I-related service companies, for the purpose of recording and evaluating present-day practices.

Task 4 - Provide actual field information on the implementation of cost-effective analytical procedures for determining necessary investments for sewer system rehabilitation vis-a-vis the cost of providing transportation and treatment of infiltration/inflow wastewater flows, by whichever means such economic alternatives are being evaluated in establishing the excessiveness or nonexcessiveness of I/I conditions in analyzed-evaluated systems.

Task 5 - Prepare a final report on the study to interpret and clarify practices and policies which have been used or should be used to analyze I/I conditions, evaluate the most effective and economical means for resolving the problems of intrusion water piracy, and the procedures by which sewer system rehabilitation, maintenance, and operation can be performed.

The purpose of this section is to describe the specific steps by which these tasks were planned and executed in order to focus on information about I/I control practices and to develop the most helpful guidelines on improved procedures by which conformity with the requirements of PL 92-500 regulations and EPA rules can be achieved by applicants for federal grants to wastewater handling and treatment works.

Literature Search in the I/I Field

Under a subcontract, Indiana University conducted a comprehensive literature search and review of recorded documents relating to all phases of the infiltration/inflow problem and solutions thereof. Significant references were summarized in capsule form to present the pertinent information and are included in the appendices published separately by NTIS.

Products and Equipment

With increasing interest in investigation, evaluation, and correction of infiltration/inflow conditions in sewer systems on the part of owners, designers, constructors, and regulatory agencies, it was apparent that guidance was needed in the field concerning the equipment, methods, and materials available to carry out studies of this problem and to initiate corrective measures.

Staff representatives interviewed exhibitors at the APWA 1974 Congress at Toronto, and the Water Pollution Control Federation 1974 Conference at Denver, who offered materials, mechanisms, and methods for I/I control purposes. Literature was solicited and interpreted and personal interviews with exhibitors disclosed additional information. In addition, manufacturers and service organizations were contacted by mail and catalog data, brochures, reports, and other documents were requested.

The product and service information was collated under six categories of I/I control functions for clarity and guidance purposes: Detection and Analysis of I/I; Sewer System Evaluation; Sewer System Cleaning; Sewer System Rehabilitation; Construction; and Safety.

The need for a comprehensive consolidation of product and service information, in the form of an overall equipment and product manual, including interpretive data on how materials, mechanisms, and methods can be used for all facets of I/I investigative and corrective work, was recognized. As a result, the development of a comprehensive document was authorized and has been published under separate cover as EPA-600/2-77-017c, Product and Equipment Guide.

Field Investigations

To determine the policies and performance of I/I survey-evaluation-rehabilitation activities, field investigations were conducted at municipalities, consulting engineering offices, state regulatory agency headquarters and sewer service firms.

The consulting engineering organizations surveyed were chosen to provide a representative cross section of design and I/I study experience in terms of geographical location of their practices, sizes of municipal systems served, and reported experiences disclosed by inquiries. The firms covered by on-site investigators were: Wallace and Associates, Virginia, Minnesota; Camp Dresser and McKee, Boston, Massachusetts; Elston T. Killam Associates, Millburn, New Jersey; Consoer, Townsend & Associates, Chicago, Illinois; and Gannett, Fleming, Corddry and Carpenter, Harrisburg, Pennsylvania.

In addition to these office interviews, other consulting engineering firms (C.E. Maguire, Inc., Waltham, Massachusetts, for Fall River, Mass.; and Mingus Associates, Farmington, Connecticut, for Norfolk, Conn.) were visited because they possessed key information on I/I studies conducted for some of the municipalities chosen for that portion of the national on-site investigations.

The state water pollution control agencies chosen for on-site surveys were intended to provide a revealing mix of geographical locations and problems, sizes of state involved, and unusual policies on I/I control. For these reasons the following state entities were investigated: Florida Water Pollution Control Department; New Hampshire Water Supply and Pollution Control Commission; and Wisconsin Water Pollution Control Agency. These investigations served a dual purpose; they disclosed state policies and practices, and they provided a broad-gauged evaluation of the status of I/I studies in their states and their experiences in dealing with EPA regional offices.

States were requested to "nominate" communities within their boundaries which were known to have engaged in the control of I/I through surveys of sewer system conditions or through routine preventive maintenance procedures. In addition, the Technical Advisory Committee members were polled concerning outstanding I/I studies conducted at the local level. Supplementary choices were based on early responses to a nationwide I/I mail survey questionnaire described below.

Out of these and other sources, sixteen municipal or multi-municipal systems were chosen for on-site investigation. The surveyed authorities were: Minneapolis-Saint Paul Metropolitan Waste Control Commission; Des Moines, Iowa; Oakland County, Michigan; Conway, Arkansas; Little Rock, Arkansas; South Tahoe Public Utility District; Fort Lauderdale, Florida; Emmetsburg, Iowa; Fall River, Massachusetts; Knoxville, Tennessee; Portland, Oregon; Longview, Texas; Richmond, California; Norfolk, Connecticut; Tampa, Florida; and New York, New York.

A mail survey of approximately 200 agencies was also conducted.

It was found that few correlations could be developed concerning the experiences and practices of the interviewed and surveyed communities. This was due in part to the state of knowledge at the time of the survey. Field interview reports are contained in the appendices to this volume published by NTIS. Limited results of the survey are contained herein under Section III.

Cost-Effective Analysis

The definition of "excessive I/I" by USEPA is based, not on volume of wastewater intrusion in sewer systems, but on the comparative costs of eliminating all or part of this I/I, vis-a-vis the cost of transporting and treatment. Thus, the decision as to sewer system rehabilitation or treatment works enlargement is based on economic factors. Rational cost-effective determinations must be made. The study plan included the development of data on a typical I/I problem and the evaluation of cost-effective factors for either sewer system rehabilitation or treatment and transportation in collector and interceptor sewers of the excess flows.

Particular emphasis was placed on the cost-effectiveness facet of the on-site investigations of municipal agencies, consulting engineering firms and state regulatory agencies. It was deemed most productive to utilize this broad-based approach to the cost analysis problem rather than utilize a single community problem as the basis for a typical cost-effectiveness analysis. The investigations demonstrated that many factors can affect the cost-effectiveness determination procedures and accordingly, no single approach can be considered representative of all analytical methodologies.

Section IV of this report contains various examples of studies of economic alternatives of various kinds, applicable to several conditions, as found in the field.

Root Control Practices

A mail questionnaire on root control practices was sent to older cities where it might be expected that roots were a problem. On the basis of the replies, 20 follow-up field investigations were conducted to explore in depth the unique problems or methods used to minimize root problems.

The results and conclusions of the survey are given in Section V.

Tide Gate and Backwater Flow Control Facilities

Tide gates or backwater flow controls are used on many systems where combined sewers or bypasses discharge to tidal waters or major rivers. Previous studies have indicated that malfunctioning facilities contribute large amounts of extraneous flow to their system. Such conditions are often noted where salt waters enter the system and disrupt secondary wastewater treatment processes.

The consulting engineering firm of C. E. Maguire was retained to prepare a report based upon a mail survey of 100 communities, field visits to six communities known to have taken action to improve their systems and their own study. The results are presented in Section VI.

Technical Advisory Committee

Much of the progress in the elimination of future infiltration into new sewer systems and the minimization of existing infiltration conditions will depend on materials of construction; equipment for installations; instrumentation; mechanisms for seeking out infiltration and inflow; methods for evaluating I/I conditions and materials and devices for rehabilitating defective sewers, joints, manholes, and other entry points of unwanted waters.

In recognition of the important role which manufacturers of such facilities and the part which engineering designers play in I/I control, a Technical Advisory Committee (TAC) was created, composed of representatives of involved manufacturing and sewer service companies and consulting engineering firms closely identified with this field. Membership is designated in the Acknowledgements.

The TAC body was divided into specialized subgroups, covering Sewer System Evaluation; Sewer System Rehabilitation; and Construction. These groups met independently to develop guidance information for the study. The data they produced is presented in the Manual of Practice.

SECTION III

ANALYSIS OF SURVEYS

For the purpose of obtaining general information on I/I causes and effects in representative sewer systems in the United States and evaluating the preventive, corrective, and regulatory practices in effect, a mail survey was conducted in January 1975.

The questionnaire was sent to approximately 200 communities recommended by state water pollution control agencies as having experienced I/I problems and having information available. A total of 117 replies were received, of which 99 contained usable information.

Status of I/I Investigation

Fifty-six communities reported that preliminary I/I surveys had been completed. Of these, 16 were carried out by in-house staffs and consultants. Generally, the entire system had been studied at least in preliminary form.

Some of the systems that had commenced preliminary I/I studies prior to requirements of PL 92-500 and USEPA continued them thereafter. Percentages of the systems studied varied between 7 and 100 percent. Of those answering the specific question, 14 stated that the work was carried out to comply with local requirements, four because of lack of sewer system or treatment plant capacity, and four for both these reasons. Zonal differences were not significant.

Twenty communities indicated that they had extended system analyses (Phase I), to evaluation surveys, Phase II. Of these, 15 performed the studies themselves, four through consultants, and one was a joint effort. Four communities reported that they carried out evaluations for legal reasons, seven for reasons of capacity, and six for both reasons. The portion of the systems studied varied between 25 and 100 percent.

Of the 17 communities reporting inflow reduction studies, only one assigned the work to consultants; all the others were carried out in-house. Seven communities reported that the work was performed under the terms of Pl 92-500; eight communities reported nonconformity with federal guidelines. The extent of the systems studied varied between 25 and 100 percent. The reasons given for inflow investigations were as follows: two of the systems were studied for legal reasons, eight for capacity, and four for both reasons.

Sources of I/I

Table 1 lists the responses received concerning the sources of I/I.

Table 1. Infiltration/Inflow Study-Ranked Major Sources of I/I

Infiltration Sources (mentioned more than once)	Total	%	Inflow Sources	Total	%
A. Pipe defects, deterioration, also broken pipe, open joints	39	39	A. Foundation drains (footer drains)	8	8
B. Leaky manholes	27	25	B. Roof leaders, drains including cellar drains	15	14
C. Defective service connections	25	23	C. Manhole covers of "open" type	24	23
D. Root Intrusions	2	1.8	D. Cleanouts on private property	4	4
E. Poor construction practice including porous pipes	27	25	E. Illicit and illegal connections	13	12
F. Soil conditions	7	6	F. Cross connections (bypasses)	7	7
G. Oakum sewer joints	1	0.9	G. Overflow structures	4	4
			H. Catch basins	12	12
			I. Street Inlets	6	6
			J. Yard drains	10	10

Cost of I/I Corrections

Table 2 lists the basic information received concerning the cost of the solution and methods considered. Only a small number of those answering the questionnaire provided cost information.

Table 2. Results of I/I Studies Summary

						Methods Considered	
City and Population Served		Infil. Correction	Inflow Correction	WWT Increase	Total Cost	Storage/ Surge	WWT Plant
Oakland, Ca.	Cost	$6,000,000	$20,000,000	$102,000,000	$128,000,000	Yes	Yes
(362,000)	$/Capita	16.57	55.25	281.78	353.59		
Truckee, Ca.	Cost	192,000	45,000	470,000	707,000	Yes	Yes
(7,000)	$/Capita	27.43	6.43	67.14	101.00		
Willets, Ca.	Cost	540,000	28,000	740,000	1,308,000	Yes	Yes
(3,600)	$/Capita	150.00	7.78	205.56	363.33		
San Mateo, Ca.	Cost	N/A	N/A	5,000,000	5,000,000	No	Yes
(80,000)	$/Capita			62.50	62.50		
Athens, Al.	Cost	N/A	N/A	3,500,000	3,500,000	Yes	No
(16,000)	$/Capita			218.75	218.75		
Ft. Worth, Tx.	Cost	7,000,000	Incl. in Infil. Column	12,000,000	19,000,000	No	Yes
(410,000)	$/Capita	17.07		29.27	46.34		
Longview, Tx.	Cost	N/A	546,000	3,353,000	3,899,000	Yes	Yes
(52,300)	$/Capita		10.44	64.11	74.55		
Hot Springs, Ar.	Cost	4,000,000	N/A	N/A	4,000,000	Yes	Yes
(37,000)	$/Capita	108.11			108.11		
Jesup, Ga.	Cost	250,000	100,000	300,000	650,000	No	Yes
(8,000)	$/Capita	31.25	12.50	37.50	81.25		
Cocoa Beach, Fl.	Cost	130,000	N/A	N/A	130,000	No	Yes
(18,000)	$/Capita	7.22			7.22		
St. Petersburg, Fl.	Cost	4,300,000	N/A	N/A	4,300,000	No	Yes
(275,000)	$/Capita	15.64			15.64		
Tampa, Fl.	Cost	3,750,000	100,000	N/A	3,850,000	No	No
(280,000)	$/Capita	13.39	0.36	N/A	13.75		
Trenton, NJ	Cost	1,600,000	N/A	N/A	1,600,000	Yes	Yes
(85,000)	$/Capita	18.82			18.82		
Warren Twp. NJ	Cost	40,000	N/A	260,000	300,000	No	Yes
(6,000)	$/Capita	6.67	N/A	43.33	50.00		
N. Attleboro, Twp., Ma.	Cost	990,000	N/A	N/A	990,000	No	Yes
(13,500)	$/Capita	73.33			73.33		
Pueblo, Co.	Cost	2,000,000	10,000,000	1,800,000	13,800,000	No	Yes
(97,500)	$/Capita	20.51	102.56	18.46	141.54		
Loveland, Co.	Cost	N/A	N/A	3,000,000	3,000,000	No	Yes
(22,000)	$/Capita			136.36	136.36		
E. Greenwich, Co.	Cost	95,000	40,000	1,000,000	1,135,000	No	Yes
(3,500)	$/Capita	27.14	11.43	285.71	324.29		
Ft. Wayne, In.	Cost	N/A	N/A	9,000,000	9,000,000	Yes	Yes
(213,000)	$/Capita			42.25	42.25		

(continued)

Table 2 (Continued)

City and Population Served		Infil Correction	Inflow Correction	WWT Increase	Total Cost	Methods Considered Storage/ Surge	WWT Plant
Norfolk, Va.	Cost	N/A	N/A	1,500,000	1,500,000	No	Yes
(800,000)	$/Capita			1.88	1.88		
College Pl.,Wa.	Cost	10,000	10,000		20,000	No	No
(4,800)	$/Capita	2.08	2.08		4.16		
Moses Lake,Wa.	Cost	50,000	50,000	2,000	102,000	No	Yes
(14,000)	$/Capita	3.57	3.57	0.14	7.28		
Gunnison, Co.	Cost	N/A	N/A	105,000	105,000	Yes	Yes
(5,000)	$/Capita			21.00	21.00		
Jamestown, RI	Cost		308,000	1,400,000	1,708,000	Yes	No
(2,200)	$/Capita		140.00	636.36	776.36		
Honolulu, Hi.	Cost	N/A	N/A	17,700,000	17,700,000	No	Yes
(531,600)	$/Capita			33.30	33.30		
Fairbanks, Ak.	Cost	N/A	N/A	3,500,000	3,500,000	Yes	Yes
(1,200)	$/Capita			2,916.67	2,916.67		
Des Moines, Ia.	Cost	N/A	N/A	900,000	900,000	No	Yes
(201,400)	$/Capita			4.47	4.47		
Webster City,Ia.	Cost	N/A	N/A	513,000	513,000	No	Yes
(8,900)	$/Capita			57.64	57.64		
Duluth, Mn.	Cost	725,000	46,000	59,965,000	60,736,000	Yes	Yes
(100,000)	$/Capita	7.25	0.46	599.65	607.36		

Root Control

Table 3 summarizes the data from the 64 reporting communities. Most communities do not maintain house laterals. Where house laterals are maintained, a large number of dig-ups can be expected. St. Petersburg, Florida reported 1,200 dig-ups per year for the portion of the lateral in the public right-of-way.

Table 3. Root Control

Number of Communities	Root Control Program in Collection System		Root Control Program in House Laterals			Dig-Ups Per Year in Collection System	Dig-Ups Per Year In House Laterals
	Yes	No	Yes	No	No Answer		
64	32	32	8	48	8	3,909	1,381

Table 4 summarizes the percentage of system subject to and requiring maintenance for root intrusion. House laterals are shown to have more root intrusion problems than collection sewers.

Table 4. Percentage of System Subject to and Requiring Maintenance for Root Intrusion

Number Communities	Average % of System			
	Subject to Root Problem		Requiring Maintenance	
	Collection System	House Laterals	Collection System	House Laterals
64	26.6	42.2	16.4	13.8

Forty-seven communities reported that they use rodding to control roots; 27 employ chemicals; jetting, buckets, and flushing are used in only a few communities. Few communities are satisfied with the procedures; the general reaction is that "nothing better is available."

A supplementary study of the sewer root problem was conducted to augment the information obtained by the subject mail survey and is contained in Section VII.

Tide Gates

A few communities employ tide or backwater gates to prevent backwater intrusion. One community reported 35 percent of inflow from this source; another reported 2.5 percent due to backwater effects. Information received on this subject is regarded as unsatisfactory and no conclusions can be drawn. A separate survey of tide gate or backwater gate problems and practices was conducted, and the results are contained in Section VIII.

Rehabilitation of Sewers

Thirty-five surveyed communities have employed chemical grouting for infiltration control. Thirty communities have used AM-9 and eight communities have used or are experimenting with 3M Elastomeric sealing compound.

Of those using AM-9, 13 reported good results, three excellent, two fair, and four poor. Those using 3M reported one excellent, one good, and one poor result.

Some communities reported use of nonchemical methods. Dallas, Texas reported good results with slip linings; Portland, Oregon reported poor results with grout lining; Seattle, Washington reported good results (90 percent effective) with cement grouting.

Of the 117 communities, 28 (24 percent) had active rehabilitation work underway while four (3 percent) were in the planning stage. The balance (73 percent) had not advanced to sewer system rehabilitation. Of the communities having work underway, seven were conducting smoke or dye tests; one was engaged in a relining program; 10 were rehabilitating manholes; four were conducting a campaign to discontinue floor and roof drain connections; one was installing backwater or flap valves; and five were attacking the problem in miscellaneous other ways.

House Laterals

The mail survey questionnaire posed a series of questions about house lateral contributions to infiltration and house connection contributions to inflow.

Insofar as house laterals are concerned, they vary in length from 15 to 150 ft (4.5 m to 45 m), with an average length of 51.5 ft (15.7 m), and they are laid at an average depth of 5.1 ft (1.5 m).

Three communities reported that house laterals contribute 55 percent of the infiltration, others stated that they contribute a substantial amount. Factual information was limited.

As far as house connections are concerned, 22 communities reported that they are enforcing, or are in the process of amending, their ordinances to reduce this source of inflow. Several communities have assigned inspection crews. Only two communities are requiring removal of roof leaders from sanitary sewer lines.

Prevention of Infiltration

Proper pipe selection and good construction practices can minimize infiltration. Pipe types such as asbestos-cement, plastic, ductile iron, and truss pipe were reported to be increasing in use. The use of vitrified clay and concrete is also widespread when used with rubber jointing rings (gaskets) and neoprene "O" rings. Both conventional bell-and-spigot and compression-type joints are used.

Bedding practices now stress the placement of granular material in the trench, particularly in the pipe zone. Sand, fine gravel, and crushed stone and stone dust are used. A few still use selected soil; one community reported the use of lean concrete.

Precast concrete with rubber gasketing, and poured-in-place concrete are both being used for manhole construction. Judging from the survey data, brick construction appears to be declining.

Jointing practices reportedly favored mechanical joints, slip joints, flexible joints, PVC couplings and adapters, fabricated polyurethane compression joints and grouting (concrete and AM-9).

In Ohio, saddles are used and encouraged. With reference to service connection construction, cast iron pipe was reported to be widely used, as is vitrified clay pipe, PVC pipe, and asbestos-cement. Insofar as jointing is concerned, rubber rings, neoprene "O" rings, mechanical compression and chemical welded joints were reported in favor, to the exclusion of cemented joints. Lead oakum joints are only occasionally employed.

To minimize infiltration in building connection lines, inspection is normally required. Of 68 communities reporting, 52 use visual inspection; seven employ smoke, air or water testing; one has TV inspection; and three use miscellaneous methods. One community requires no testing; four leave inspection and approval to building or plumbing inspectors.

As to the method of connecting building service lines to the sewer system, a wye or tee connection is the most popular in 36 out of the 60 reporting, 14 require saddles, and 10 employ individually developed methods.

The design allowable infiltration rate varied from 5,000 gal/in-diam/mi/day (4.75 m^3/cm-diam/km/day) down to nil.

The methods used for Inspection/Acceptance Testing in 73 communities are listed in Table 5. Note: most of the communities use more than one method.

Table 5. Inspection/Acceptance Testing

Infiltration	Exfiltration	Air Testing	TV Photo	Other, Mostly Visual
48	41	36	36	17

SUMMARY

A mail survey of 200 local authorities recommended by state water pollution control authorities resulted in 99 usable replies. Data from the replies indicated that the local conditions which have caused infiltration and inflow problems are too complex and too localized to be able to make broad characterizations of conditions. Although climate was used to analyze the data it was found that it was not in itself a good indicator of conditions which could be anticipated.

The authorities which responded do not constitute a statistical sample as the interest of the survey was to obtain a broad cross section of current practice by knowledgeable agencies. Over half had completed preliminary studies and one-fifth had begun evaluation surveys. Studies of infiltration conditions had been generally conducted by consultants whereas for inflow, the local authorities generally conducted the work.

The amount of infiltration reported ranged from 14 to 70 percent of the total WWF with an average of 71 percent of peak DWF. Inflow averaged 144 percent of the peak DWF, highlighting the importance of such flows. Sources and conditions resulting in 1 to 1 conditions were identified and quantified. Manhole covers were mentioned by 25 percent of those who replied. House laterals were identified often as a major source of infiltration. Cost information concerning correction or control alternatives were sparse and meaningful conclusions could not be drawn.

Sewer maintenance activities appear to receive increased resources and concern as the extent of the 1 to 1 problem becomes known. There is general use of high pressure cleaning equipment. Responsibility for the lateral either on private property or in the public way varies widely. Where such lines are the public's responsibility they often constitute a major maintenance problem.

Roots and tide gates were identified as problem areas. Authorities surveyed had relatively minor experience with sewer grouting.

Most authorities reported upgrading of specifications for new sewer work along with more stringent infiltration allowances. Acceptance testing methods varied with no one method predominantly used.

SECTION IV

ECONOMIC GUIDELINES

The Economic Factors Involved

When excessive amounts of I/I waters enter sanitary or combined sewer systems, the immediate effects are "physical." As important as these physical effects on the capacities and capabilities of sewer conduits, pumping facilities, treatment works, and regulator overflow structures may be, the full impact of such extraneous waters cannot be known until the "financial" factors are computed and evaluated.

The hidden costs of I/I usurpation of system capacities and capabilities generally have been overlooked when corrective action is planned. Even the readily computable costs seldom have been evaluated and properly interpreted in terms of the economics of urban services.

Where preventive measures have been taken to reduce infiltration in new sewer systems, designers and utility officials have been concerned about any added cost of projects because of specification requirements for tighter lines. Little consideration has been given to immediate and long-range savings that might accrue in terms of reduced size of new sewer lines and longer service life of such systems.

If and when correction of infiltration in existing overtaxed sewer systems has been considered or undertaken, the usual concern has been the immediate and direct expenditure for sealing or replacing defective sewer structures. Little thought has been given to the long term evaluation of costs versus the benefits to be derived in sewer system service and in the pumping and treatment of wastewater. Few jurisdictions actually have evaluated the volumes of flow due to infiltration and inflow or the marked economic effect of such flows. Now PL 92-500 and USEPA guidelines require studies of the cost-effectiveness of corrective actions, vis-a-vis the costs involved in system rehabilitation and the treatment of intruded flows.

In terms of local effects of surcharged sewer systems, emphasis has usually been placed on the adverse effects to the public which uses thoroughfares and on property owners inconvenienced and injured by back-flooding into their properties. Unfortunately, the monetary costs of these adverse effects have seldom been identified.

No meaningful evaluation of this problem, in all of its ramifications and implications, can be made without considering the costs of such intruded flows and the capital investments required to eliminate or alleviate the difficulties previously mentioned.

The evaluation of the economic factors of I/I has, in the past, been given little attention. This stems partly from the unavailability of rational fiscal guidelines that will permit the computation of the tangible costs of handling excessive amounts of extraneous waters. Such costs must be balanced against the cost of constructing relatively infiltration-free sewer systems in the future and financing projects to correct I/I conditions in existing systems.

It is true that present capabilities for developing such fiscal comparison guidelines are not substantially better than in the past; however, heightened environmental awareness on the part of the general public, in concert with the manifestations of population growth and creeping urbanism, has now made some practices unacceptable, that once were commonplace. For example, when only primary treatment of municipal sewage flows was deemed adequate, the periodic discharge to local receiving waters of sewage untreated but extensively diluted by the presence of I/I was considered an allowable practice. There is now widespread concern for the threats posed to receiving waters from untreated discharges, consequently water quality standards have become stringent, necessitating in most instances substantial increases in the extent and cost of wastewater treatment prior to discharge. With this increase has come the realization that the costs and benefits associated with wastewater treatment and conveyance should be more fully explored and should be the primary determinant in wastewater management decision making.

Thus it is that I/I poses problems of both environmental and economic significance. They include, but are not limited to the following:

1. Increased size and cost of new sewers if excessive I/I are permitted.
2. Need for construction of relief or supplementary collection and interceptor sewers earlier than the originally estimated economic life of existing sewers.
3. Operation and maintenance costs for handling local sewer surcharges, clean up of flooded areas, and damages to flooded private properties.
4. Increased operation and maintenance costs for pumping excess flows.
5. Cost of repairing pavement cave-ins and washouts of subsurface utilities caused by infiltration and exfiltration.
6. Cost of removing soil, debris, and tree roots entering sewers through defective sewer pipes and joints.
7. Cost of excessive wear on pumping station equipment and power requirements.
8. Increased operation and maintenance costs at wastewater treatment plants.
9. Need for increases in treatment capacity because systems are overloaded with excessive I/I volumes.

The USEPA requires that communities seeking matching funds for wastewater treatment plant construction or renovation must engage in facilities planning. Included in this planning is a description of all elements of the system, from the service area and collection system, through treatment, to the ultimate discharge of treated wastewaters and disposal of sludge. Applicants must demonstrate that each sewer system discharging into the treatment works is not, or will not be, subject to excessive I/I.

The determination of whether excessive I/I exists may take into account, in addition to flow and related data, other factors as public health emergencies, the effects of plant bypassing or overloading, and other relevant economic or environmental factors. Of paramount importance is a determination of the cost-effectiveness of sewer system rehabilitation versus the handling of I/I by means of enlarged sewers and treatment facilities.

Excessive I/I is defined primarily as that portion of the flow that can, by corrective measures, be removed or excluded from the system more economically than it can be transported to and treated at the treatment works.

The basic components of a sewer system evaluation survey and I/I analysis are fully identified in the Construction Grant Regulations and are not elaborated here. These regulations are updated or changed from time to time and care must be used to determine that current regulations are being adhered to. It is important to note, however, that the I/I analysis is based principally on currently available information such as flows, population served, age, and condition of the sewer system. It serves as a preliminary indication of possible excessive I/I.

If the analysis reveals the possible existence of excessive I/I, a detailed evaluation must be performed to ascertain the extent of I/I, necessary remedial measures, and the associated costs. Thus, a two-step process is involved in the identification and the quantification of any sewer system's I/I problem.

The economic evaluation utilizes a cost-effectiveness approach to I/I reduction and/or treatment. Its elements are detailed in the construction grants regulations and include suggested unit costs for system rehabilitation and treatment plant facilities. In the following portions of this section, the principal elements of the cost-effectiveness analysis are discussed and illustrated in the context of an example community. The cost assumptions and other factors used in the example may or may not reflect conditions in any specific individual jurisdiction system. Each community has its own cost experiences, sewer system needs, pumping, and treatment requirements and other local or indigenous factors. Such specific factors should be used to replace the arbitrarily chosen physical and economic assumptions used in the following sample analysis.

Cost-Effectiveness Analysis

The purpose of a cost-effectiveness analysis is to determine which of all feasible wastewater management systems (or component parts thereof) would, if adopted and implemented, result in the minimum total resource costs over time, and meet applicable federal, state, and local requirements for pollution abatement. Included in the resource costs are those expressible in monetary terms, such as capital and operating costs, and in nonmonetary terms, such as social and environmental costs. Monetary costs are presented as present worth values (equivalent annual costs) calculated on the basis of a 20 year planning period and an interest (discount) rate as promulgated by the Water Resources Council for use in water resource projects. Nonmonetary costs are accounted for descriptively.

The most cost-effective alternative is the one determined from the analysis to have the lowest present worth (or annual cost) without overriding adverse nonmonetary costs and realizing at least identical minimum benefits in terms of applicable federal, state, and local standards for effluent quality, water quality, and other provisos.

Acceptable ranges of service life for treatment works are: land, permanent-structures, 30-50 years; process equipment, 15-30 years; and auxiliary equipment, 10-15 years. Other service life criteria are acceptable if sufficiently justified. Salvage values are based on straight-line depreciation except that land for treatment works shall have a salvage value equal to the prevailing market value at time of the analyses, and rights-of-way values are assumed to be not greater than the prevailing market value.

Example of Community Profile

Example cost-effectiveness analyses are presented in the remainder of this section. The calculations are based on an example community, as outlined in Table 6. While similar information would be needed as background for an I/I analysis and/or any required system evaluation survey, the profile as shown should not be regarded as a complete example of these background requirements.

The cost-effectiveness analysis that follows is based on the premise that the community is presently served by a 10 mgd (438 l/s) design flow activated sludge plant. A plant expansion of 7 to 17 mgd (307 to 745 l/s) design flow is proposed to meet existing flows (including I/I) and provide for anticipated community growth. As proposed, the expanded plant would provide secondary treatment for 10 years, until 1985, and tertiary treatment thereafter. In all cases, peak flow capacity of the plant is taken to be twice the design flow capacity.

Since the proposed plant expansion to 17 mgd (745 l/s) design flow includes all existing I/I, the analysis must weigh the costs of I/I reduction against the savings in capital and operating costs of treatment gained through I/I flow reductions and the decreases in plant design capacity they permit. The costs associated with transporting the excessive I/I to the treatment facility, or the savings gained by no longer doing so should also be included.

In general, all costs presented in the analysis should be itemized to the greatest degree practicable. For the example only representative itemization has been used.

Table 6. Community Profile and Explanatory Key

A. Community Profile

	Population	100,000	
1.	Area (acres)	12,000	(4856 ha)
2.	Density (persons/acre)	8.3	(20.5 per/ha)
3.	Housing Units (3.5 persons/unit)	28,570	
4.	Housing Structures (75% of units)	21,430	
5.	Mfg. Establishments	112	
6.	Business Establishments	1,470	
7.	Business Structures (75% of est.)	1,100	
8.	All Structure Connections (ft/structure)	60	(18 m/stru)
9.	Diameter (inches)	6	(15.2 cm)
10.	House Connections (feet)	1,285,800	(391,912 m)
11.	Mfg. Connections (feet)	6,720	(2048 m)
12.	Business Connections (feet)	66,000	(20,117 m)
TOTAL 6 inch			
	Building Sewer Connections	1,368,520	(m)
	Municipal Systems		
13.	Sewer Miles/acre	0.022	(087 km/ha)
14.	Total Sewer Miles	264	(425 km)
15.	Pipe Size as Percent of Total System (feet)		
	6 to 8 in. @ 75%	1,045,440	(0.15 to 0.2 m)
	10 to 12 in. @ 14%	195,149	(0.25 to 0.3 m)
	15 to 18 in. @ 6%	83,635	(0.4 to 0.69 m)
	21 to 27 in. @ 4%	55,757	(0.53 to 0.69 m)
	30 to 42 in. @ 1%	13,939	(0.76 to 1 m)
Total Length of Sewer Sys.		1,393,920 ft	(425 km)
16.	Manholes	3,485	

B. Explanatory Key

1. *Area* – Average sewered area of cities in this population range. Taken from a survey summary prepared by APWA for a study on combined sewer overflows. *Problems of Combined Sewer Facilities and Overflows 1967.* Federal Water Pollution Control Administration, U.S. Dept. of the Interior; December, 1967.
2. *Density* – Based on average area and population by city size, from overflow report summary (Ibid).
3. *Housing Units* – Average for all SMSAs in 1960. *1960 Census of Housing.* Bureau of the Census, U.S. Dept. of Commerce.
4. *Housing Structures* – Average for all SMSAs in 1960 (Ibid)
5. *Manufacturing Establishments* – Based on average number for appropriate SMSA size. Each establishment assumed to occupy separate structures. *1963 Census of Manufacturers.* Bureau of the Census, U.S. Dept. of Commerce.
6. *Other Business Establishments* – Based on average number of retail and service establishments by appropriate SMSA size. *1963 Census of Business,* Bureau of the Census, U.S. Dept. of Commerce.
7. *Other Business Structures* – Assumed to be 75 percent of business establishments.

8/
9. All connecting sewers were assumed to be 6 in. (15 cm) vitrified clay pipe with a length of 60 ft (18 m) between the structure and the municipal sewer.
10. Presented in feet. Number of structures times 60 ft (18 m).
11. Presented in feet. Number of structures times 60 ft (18 m).
12. Presented in feet. Number of structures times 60 ft (18 m).
13. *Sewer Miles/Acre* – Based on overflow survey cited in (1) above.
14. *Total Sewer Miles* – Sewer miles/acre, times average area.
15. *Pipe Size and Percent of System* – Average sizes as percent of system based on U.S. totals estimated by BSDA. Picton, Walter L.; "2.7 Billion Feet of Sewer Pipe Will Serve Communities by 1975." *Wastes Engineering.* November, 1959.
16. *Manholes* – One manhole for each 400 ft (122 m) of municipal sewers. Merritt, Frederick S. Ed. *Standard Handbook for Civil Engineers.* New York: McGraw-Hill Book Co. 1968

Treatment Costs

The capital costs of primary and secondary treatment are based on a study conducted by the U.S. Public Health Service in 1964(2). The cost of tertiary treatment has been estimated at 100 percent of the costs of primary-secondary treatment in 1969 (3). Plant operating and maintenance costs are based on a study carried out by P. P. Rowan, K. L. Jenkins, and D. H. Howells of the Public Health Service in 1961(4). The operating costs of tertiary treatment are again assumed to be 100 percent of primary-secondary treatment.

The capital costs of primary and secondary facilities were computed on a per capita basis. These were converted to gallons per day by assuming an average flow of 100 gal/day/person (379 l/day/person). Operation and maintenance costs also were computed on a per capita basis. Regardless of the sources of flow to the plant, the analysis gives a basis for making decisions as to the effect of I/I volume on increased plant costs.

Capital Costs

As stated previously, the capital costs were based on a Public Health Service study. Data on activated sludge plants were available from 133 construction projects in all parts of the country. These projects represented design populations up to 100,000. The expected costs were estimated by regression analysis from the formula:

$$\log 10y = 3.6533024 - 0.2782395 \log X$$

y = expected per capita cost

X = design population

r = coefficient of correlation = (0.73)

The resulting values represent contract construction costs. Not including engineering, legal, and administrative costs, and land acquisition cost. The study points out that the nonconstruction costs, exclusive of land, could add 20 percent to the expected costs. These costs have been added, as well as 10 percent for land acquisition. All study capital costs were stated in 1957-59 dollars. The costs presented herein were inflated to 1975 levels using the USEPA treatment plant United States cost index (1975 = 232).

Present worths of capital costs are based on an average useful life of 20 years and a 7 percent interest rate, despite the fact that the officially established interest rate for water resources projects is considerably lower at present 5.875 percent in fiscal year 1975.

The capital cost of expanding the activated sludge plant is calculated as the difference between the capital costs of the two sizes as estimated by the equation described previously. Added to this are engineering costs (20 percent) and land acquisition costs (10 percent), a total of 30 percent of the expansion costs. The salvage value of the land, calculated as the present worth of the incremental land costs associated with plant expansion, is deducted to arrive at the total present worth of the capital costs. No other salvage values are claimed.

The following is an illustration of the calculations involved in estimating the present worth of capital costs associated with expansion of an activated sludge plant from 10 mgd to 17 mgd (438 l/s to 745 l/s) design flow.

For a 17 mgd plant (745 l/s); equivalent population = 170,000

$\log 10\ y = 3.6533024 - 0.2782395 \log(170{,}000)$

$y = 15.776$ = per capita cost (1957 - 1959 dollars)

Capital cost (1957 - 1959 dollars) = 15.776(\$170,000) = \$2,682,000.

Capital cost (1975 dollars) = 2.32(\$2,682,000) = \$6,222,000.

For a 10 mgd plant (438 l/s); equivalent population = 100,000

Per capita cost = \$18.285 (1957-1959 dollars)

Capital cost (1975 dollars) = 2.32(\$18.285)(100,000) = \$4,242,000.

Capital cost of expansion

\$6,222,000 - \$4,242,000	\$1,980,000
Engineering and legal costs (20%) =	396,000
Land costs @ 10%	198,000
Total Capital Costs of Expansion =	\$2,574,000

Salvage value of land

The salvage value of the land required for plant expansion is, at the end of the 20-year planning period, taken to be \$198,000, the same as its current value. The present worth of this salvage value is calculated by multiplying the salvage values by a single-payment present worth factor,

$$\frac{P}{F} = \frac{1}{(1 + i)^n}$$

where: P = present worth
F = future (salvage) value
i = interest (discount) rate
n = planning period

In short, this calculation identifies the sum of money that, if placed at interest for n years, would yield an amount equal to the salvage value. Procedures for calculating present worths and tabulations of appropriate factors may be found in a variety of references (5).

For i = 0.07 and n = 20 years, the present worth of the land salvage value is:

$$\$198{,}000 \left(\frac{1}{1.07}\right)^{20} = \$198{,}000(0.253429) = \$51{,}000$$

Net present worth of capital costs (secondary treatment)

Since other capital costs are for current expenditures, they do not require discounting; and the net present worth of the capital costs for plant expansion is:

Present worth of new capital costs = \$2,574,000 - \$51,000
= \$2,523,000

The capital costs associated with the addition of tertiary treatment in 10 years (1985) is taken as equal to the capital costs of an activated sludge plant of the same design flow. Since these costs would not be incurred until 10 years into the planning period, their magnitude must be reduced to a present worth by multiplying by the single-payment present worth factor $P/F = 1/(1-i)^n$, with n = 10 years.

The service life of the tertiary facility is taken to be 20 years from the time of construction, or 10 years beyond the planning period. As a result, a salvage value is claimed for the tertiary facilities, based on straight-line depreciation of the capital costs exclusive of engineering, legal, and land costs. To this is added the salvage value of the land costs related to tertiary treatment, taken as equal to the land cost at the time of construction. The sum of the two salvage values is then converted to a present worth by multiplying by the single payment present worth factor (n = 20).

The calculations are illustrated below for a 17 mgd (745 l/s) design flow plant capacity.

Capital cost = \$6,222,000
(taken from earlier illustration, 17 mgd (745 l/s) plant)

Engineering and legal (20% of capital cost) = 1,244,000
Land costs (10% of capital cost) 622,000
Total Capital Cost \$8,088,000

Present worth, total capital cost:

$$\frac{\$8,088,000}{(1.07)^{10}} = \$8,088,00(0.50835) = \qquad \$4,112,000$$

Salvage value, tertiary facilities:

$$\left(\frac{\text{Service life - period used}}{\text{Service Life}}\right) \text{capital cost} = \text{salvage value}$$

$$\left(\frac{20-10}{20}\right)(\$6,222,000) = \qquad \$3,111,000$$

Salvage Value, Land Costs = 622,000
Total Salvage Value = \$3,733,000

$$\text{Present Worth, Salvage Value} = \frac{\$3,733,000}{(1.07)^{20}} = \qquad \$\ 965,000$$

Net present worth, capital costs = \$4,112,000 - \$965,000 = \$3,147,000

It should be noted that the projects included in the Public Health Service study were limited to those with design populations of 100,000 or less. Therefore, the values obtained for plants over 10 mgd (438 l/s) capacity may or may not reflect the actual costs of larger treatment facilities. However, the resulting values appear reasonable for illustrative purposes.

Operating Costs

Plant operation and maintenance costs are also based on a Public Health Service survey. Included in this cost evaluation were operating and maintenance costs for 60 activated sludge treatment facilities. In this study the valid design population range was up to 200,000. As before, extension of the curve may or may not accurately reflect these costs for larger plants. The expected values were estimated from the formula:

$$\log y = 1/\left[(0.50927) + 0.13791 \log X\right]$$

y = the expected annual per capita cost x 10
X = population served x 0.01 (no r is given)

All costs were stated in 1957-1959 dollars. They have been brought up to the 1975 level by use of the Bureau of Economic Affairs' Implicit Price Deflator (BEA-IPD) of state and local government purchases of goods and services (1975 = 227). Included in the operation and maintenance costs are all costs other than central administration and capital maintenance.

The annual operating cost for secondary treatment is converted to present worth by multiplying the annual cost by the series present worth factor:

$$\frac{P}{A} = \frac{(1 + i)^n - 1}{i(1 + i)^n}$$

where: P = present worth
A = annual cost
i = interest (discount) rate
n = planning period, years

The annual operating cost for tertiary treatment is assumed to equal that for secondary treatment. Since tertiary treatment is assumed to begin after 10 years, it contributes to the operating cost only for the last half of the planning period. Calculation of the present worth of this operating cost requires two steps: conversion of the annual costs to a single 1985 value using the series present worth factor mentioned above with $n = 10$; and the discounting of the 1985 value to a 1975 amount using the single-payment present worth factor described earlier (again $n = 10$). These calculations are illustrated as follows:

Operating costs, 17 mgd (745 l/s) design flow activated sludge plant:

log y = 1/(0.50927 + 0.13791 log 1,700) = 1.0474

Annual per capita cost (1957-1959)dollars = 0.1 y = 0.1(11.152) = $1.1152

Annual operating cost (1975 dollars) = 2.27($170,000)(1.1152) = $430,400

$$\text{Present worth, annual operating costs} = (\$430{,}400)\left[\frac{(1.07)^{20} - 1}{0.07\ (1.07)^{20}}\right]$$

$$= \$430{,}400\ (10.5940)$$

$$= \$4{,}560{,}000$$

Operating costs, 17 mgd (745 l/s) Tertiary Treatment Facility
(assumed to equal annual operating costs of activated sludge plant)

Present worth, Tertiary Treatment Facility Operating Costs =

$$(\$430{,}400)\left[\frac{(1.07)^{10} - 1}{0.07(1.07)^{10}}\right]\frac{1}{(1.07)^{10}} =$$

$$(\$430{,}400)\ (7.70236)\ (0.50835) = \qquad \$1{,}537{,}000$$

The net present worth for several different sizes of treatment plants, calculated in accordance with these illustrations, is summarized in Table 7. Also shown in the table are the incremental costs of changing the design capacity.

Collection System Costs

The capital or construction costs of a sewer system show wide variations among cities. Similar variations appear in sewer repair costs, due to differences in climate, topography, soil, and groundwater conditions. In the examples that follow, the sewer repair and replacement costs reflect approximate values taken from several sources. While other sections of this evaluation provide some guidance with respect to such costs, each community's own experience provides the best estimate of their magnitude. Thus, the numerical values contained in the examples are offered solely to illustrate the procedure for analysis. It is assumed that the values presented include all costs, such as landscaping and street cut repairs, and other phases of construction and reconstruction.

Among the costs associated with excessive infiltration and inflow are estimates for emergency repairs resulting from street cave-ins and for pumping and clean up due to wet-weather flooding of local areas. The annual savings for emergency street repair costs have been assumed as $250/yr/mi ($155/yr/km) of sewer repaired, or at a present worth of 7%, for 20 years, of $2,650/mi ($1,646/km). Savings of pumping and clean up costs are estimated at $5,000/yr/mgd ($114/yr/l/s) of I/I removed or excluded, or a present worth of $53,000/mgd ($1,210/l/s). These figures were taken from approximations and, as before, the community's own cost experiences should be used in making the cost-effectiveness analyses. They enter the analysis either as additions to the treatment costs, reflecting further costs associated with the I/I, or as deductions from the costs of removing or excluding I/I. The most effective

Table 7. Summary of Treatment Costs

Primary Plus Secondary Treatment				Tertiary Treatment (1985 on)		
Treatment Capacity mgd	Incremental capital cost: expansion from 10 mgd (438 1/s) to capacity shown	Present worth of annual operating and maintenance costs	Present worth of total costs incremental + O & M	Present worth of capital costs, tertiary only	Present worth of O & M costs, tertiary only	Present worth, total treatment costs, secondary till 1985 and tertiary thereafter
17 (745 1/s)	$2,523,000	$4,560,000	$7,083,000 (568,000)*	$3,147,000	$1,537,000	$11,767,000 (772,000)
16 (700.1 1/s)	2,183,000	4,331,000	6,514,000 (576,000)	3,021,000	1,460,000	10,995,000 (792,000)
15 (6.57 1/s)	1,838,000	4,100,000	5,938,000 (589,000)	2,883,000	1,382,000	10,203,000 (809,000)
13 (569.4 1/s)	1,127,000	3,633,000	4,760,000 (615,000)	2,600,000	1,225,000	8,585,000 (846,000)
10 (438 1/s)	---	2,914,000	2,914,000	2,152,000	982,000	6,048,000

*Numbers in parentheses indicate incremental costs of changing plant design capacity by 1 mgd (43.8 1/s).

combination of sewer repair and I/I treatment is the same by either approach. The former presents more completely the total costs of I/I, while the latter is somewhat simpler to apply to the example problem as structured here.

As stated earlier, a two step process is involved in the identification and quantification of the infiltration/inflow problem. The first step is an I/I analysis based on currently available information on flows, population served, age of system, and other factors. Estimates are made of the probable quantities of I/I in each section of the sewer system and of the expenditures needed to eliminate the I/I or reduce it to an acceptable limit. In general, the results are compiled in terms of a number of individual, separable projects that can be feasibly and rationally undertaken separately and independently. For example, if different portions of a sewer line require different types of repair and, therefore, have different associated costs, each portion is identified as a separate project. Once all the projects are identified, each is ranked according to its cost per quantity of I/I reduction gained, with the lowest cost per unit I/I first. Cumulative listings, in order of ranking of the projects' costs and I/I quantities are prepared. Following the procedure described earlier, the savings related to reductions in street cave-ins or costs of flooding cleanups are incorporated in these cumulative lists. They may be added to the treatment costs, if preferred.

For each of the projects as ranked above, the cumulative cost of collection system repair/replacement is added to the present worth of treatment costs required to treat the remaining flow not removed by repair or replacement of the collection system. The most cost-effective solution is that one for which the total costs expressed as present worth are least, assuming all projects meet the same federal, state, and local standards as a minimum and that none has overriding adverse social or environmental nonmonetary consequences. The procedure is illustrated in the following example.

Examples of Cost-Effectiveness Analyses

Infiltration/Inflow Analysis - On the basis of existing information, an I/I analysis of the example community profiled in Table 6 revealed two sectors of the community wastewater collection system that had substantial I/I. Table 8 refers to Sector 1 and Sector 2, respectively. Sector 1 involves about five percent of all building connections and smaller sewer sizes of the example community, and a lesser proportion of the larger sewer sizes. Sector 2 involves about two percent of all building connections and smaller sewer sizes and again a lesser proportion of the larger sewer sizes.

The table identifies the probable sources of infiltration by size and length of sewer, number of manholes or building connections involved; the probable quantities of infiltration for each source; and the probable costs of removing or eliminating I/I. For purposes of this example, the quantities of infiltration shown are taken to be in excess of any remaining infiltration to be expected in the sewer line after remedial measures are taken.

Table 8. Infiltration/Inflow: Quantity and Correction Costs

Sector 1

Source in.	Source (cm)	Number	Length ft	Length (m)	Infiltration mgd	Infiltration (l/s)	Unit correction $/ft	Unit correction ($/m)	method	Total corr. cost	Present worth of savings: Street cave ins	Present worth of savings: Flood clean up	Present worth net corr. costs	$/mgd	($/l)
Bldg		1132	67,926	(20,700)	1.5438	(57.60)	$600.00		service repair	$679,200	$34,090	$81,820	$563,290	$364,900	(8,331)
6 8	(15.2 20.3)		47,074	(14,400)	1.2475	(54.60)	4.65	(15.3)	grout	218,900	23,630	66,120	129,150	103,500	(2,363)
			5,227	(1,590)	0.1386	(16.00)	25.00	(82.0)	replace	130,680	2,620	7,350	120,710	870,900	(19,884)
10 12	(25.4 30.5)		4,683	(1,400)	0.1951	(8.54)	4.65	(15.3)	grout	21,780	2,350	10,340	9,090	46,600	(1,064)
			585	(180)	0.0244	(1.10)	12.00	(39.4)	reline	7,020	[illegible]	1,290	5,440	222,800	(5,087)
15 18	(38.1-45.7)		1,673	(510)	0.1045	(4.57)	40.00	(131.2)	replace	66,920	[illegible]	5,540	60,540	579,300	(13,226)
21-27	(53.3-68.6)		558	(170)	0.0507	(2.22)	60.00	(197.0)	reline	33,480	280	2,690	30,510	601,800	(13,740)
36	(91.4)		3,000	(900)	0.2045	(9.00)	70.00	(320.0)	replace	210,000	1,510	10,840	197,650	966,500	(22,066)
manholes		65			0.2772	(12.14)	500 ea		cement grout	31,500		14,690	16,810	60,600	(1,384)

Sector 2

Source in.	Source (cm)	Number	Length ft	Length (m)	Infiltration mgd	Infiltration (l/s)	Unit correction $/ft	Unit correction ($/m)	method	Total corr. cost	Present worth of savings: Street cave ins	Present worth of savings: Flood clean up	Present worth net corr. costs	$/mgd	($/l)
Bldg.		453	27,170	(8,300)	0.3088	(13.50)	$600.00	–	repair service	$271,810	$13,640	$16,370	$241,800	$783,000	(17,869)
6-8	(15.2 20.3)		20,908	(6,400)	0.2772	(12.20)	4.65	(15.3)	grout	'97,230	10,500	14,690	72,040	259,900	(5,910)
10-12	(25.4 30.5)		1,951	(590)	0.0406	(1.80)	10.00	(32.8)	line	19,510	980	2,150	16,380	403,400	(9,206)
manholes		10			0.0144	(.631)	300 ea		chemical grout	3,000		760	2,240	155,600	(3,551)

(Inflows – 1 hour storm)

Source	Number	mgd	(l/s)	Unit correction	Total corr. cost	Flood clean up	Present worth net corr. costs
House roofs	500	4.32	(18.90)	0.18 mg (681,3) @ $50/ea	$25,000	$228,960	(-203,960)
Business inflows	100	2.88	(12.6)	0.12 mg (454.2) @ $400/ea	$40,000	120,840	(- 80,840)

SUMMARY, INFILTRATION QUANTITIES AND CORRECTION COSTS

(Ranked in order of lowest cost of correction per mgd removed)

Rank	Rank Identification: Sect.	In.	(cm)	Length ft or no	Length (m)	Infiltration mgd	Infiltration (l/s)	Unit cost $/ft	Unit cost ($/m)	method	Total cost Net	$/mgd	($l/s)	Accumulated Inflow mgd	Accumulated Inflow (l/s)	Accumulated Net cost, $(P.W.)
(01)	I	10 12	(25 4-30.5)	4,683	(15,364.0)	0.1951	(8.5)	$ 4.65	(15.3)	grout	$ 9,090	$ 46,600	$(1,064)	0.1951	(8.5)	$ 9,090
(02)	I		manholes	65 @ (19) 3 gpm	(213.3)	0.2772	(12.0)	500. ea		cement grt	16,810	60,600	(1,383)	0.4723	(20.7)	25,900
(03)	I	6-8	(15.2 20.3)	47,074	(14,400.0)	1.2475	(55.0)	4.65	(15.3)	grout	120,150	103,500	(2,362)	1.7198	(75.4)	155,050
(04)	II		manholes	10 @ (06) 1 gpm	(32.8)	0.0144	(63.0)	300. ea		chem. grt.	2,240	155,600	(3,551)	1.7342	(76.0)	157,290
(05)	I	10-12	(25.4-30.5)	585	(180)	0.0244	(1.1)	12.00	(39.4)	reline	5,440	222,800	(5,085)	1.7586	(77.0)	182,730
(06)	II	6-8	(15.2-20.3)	20,908	(68,596.0)	0.2772	(12.0)	4.65	(15.3)	grout	72,040	259,900	(5,931)	2.0358	(89.0)	234,770
(07)	I		Building	1,132 units		1.5433	(67.6)	600. ea	–	repair serv.	563,290	364,900	(8,328)	3.5796	(157.0)	798,060
(08)	II	10-12	(25.4-30.5)	1,951	(6,400.9)	0.0406	(1.8)	10.00	(33.0)	reline	16,380	403,400	(9,206)	3.6202	(158.6)	814,440
(09)	I	15-18	(38.1-45.7)	1,673	(510)	0.1045	(4.6)	40.00	(131.0)	replace	60,540	579,300	(13,221)	3.7247	(163.0)	874,980
(10)	I	21-27	(53.3-68.6)	588	(170)	0.0507	(2.2)	60.00	(197.0)	reline	30,510	601,800	(13,734)	3.7754	(165.0)	905,490
(11)	II		Building	453 services		0.3088	(14.0)	600. ea	–	repair	241,800	783,000	(17,870)	4.0842	(179.0)	1,147,290
(12)	I	6-8	(15.2-20.3)	5,227	(17,149.0)	0.1386	(6.0)	25.00	(82.0)	replace	120,710	870,900	(19,876)	4.2228	(185.0)	1,268,000
(13)	I	36	(91)	3,000	(900.0)	0.20451	(9.0)	70.00	(230.0)	replace	197,650	966,500	(22,057)	4.4273	(194.0)	1,465,650

Each potential source identified in the table is regarded as a separate project, and the total costs for remedial action on that project are calculated. Deducted from these costs are the present worths of savings anticipated from the reductions in numbers of street cave-ins and costs of flood cleanups attributable to the infiltration. This yields a net cost of remedial action for each project and provides a basis for calculating the net cost per unit of flow of infiltration reduced or eliminated.

All projects are then ranked in order of increasing costs per mgd of infiltration removed, as illustrated in Table 8. The costs incurred and quantities of infiltration removed by undertaking each of the remedial projects successively in order of their ranking are accumulated.

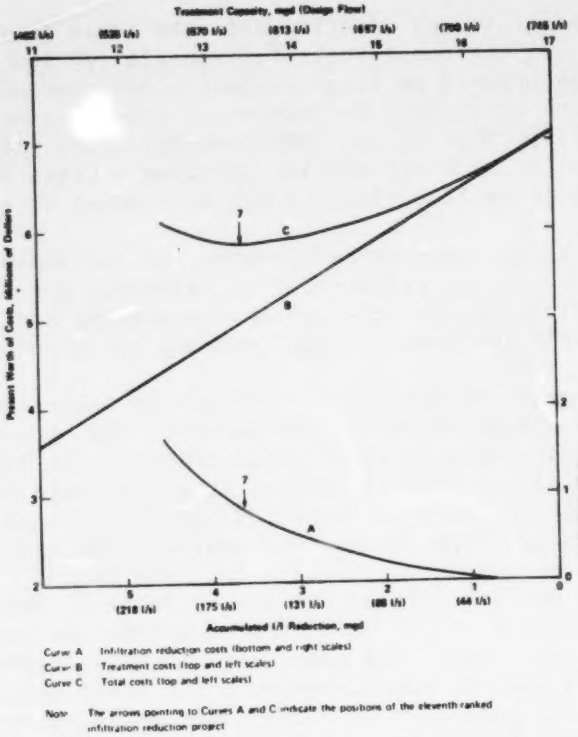
If infiltration at the rates shown in the table persists over long periods of time, possibly caused by persistently high groundwater tables, the treatment facility must be sized to accommodate the infiltration as part of the design flow. This is assumed to be the case for the present example, and so a reduction in quantity of infiltration produces an equal reduction in the design capacity of the treatment facility. The costs associated with each successive level of I/I reduction (Table 8) are added to the net present worths of treatment costs (Table 7) for plant sizes appropriate to the level of I/I reduction to obtain the overall cost of treatment and I/I reduction. The most cost-effective combination is that for which the total cost is least, assuming all other requirements discussed earlier are met. The procedure is illustrated graphically in Figure 1, for primary and secondary treatment only. Figure 2 includes tertiary treatment and follows a similar pattern.

If only primary and secondary treatment is needed to meet all federal, state, and local requirements, the most cost-effective combination of infiltration reduction and wastewater treatment is indicated by the lowest point on the total cost curve C of Figure 1. This corresponds to a reduction in infiltration of 3.58 mgd (157 l/s) and a treatment plant capacity of 13.42 mgd (588 l/s). Thus, the first seven infiltration reduction projects in order of ranking should be undertaken.

If tertiary treatment is required to meet water quality requirements, the most cost-effective combination of infiltration reduction and wastewater treatment is obtained from Figure 2. The least total cost is attained by removing 4.08 mgd (179 l/s) of infiltration, corresponding to the eleventh-ranked project in terms of accumulated infiltration reduction.

The most cost-effective level of infiltration reduction could also be determined approximately by comparing the cost per mgd of each project in ranked order as shown in Table 8 with the incremental unit flow cost of treatment shown in parentheses in Table 7 for the appropriate size of treatment facility.

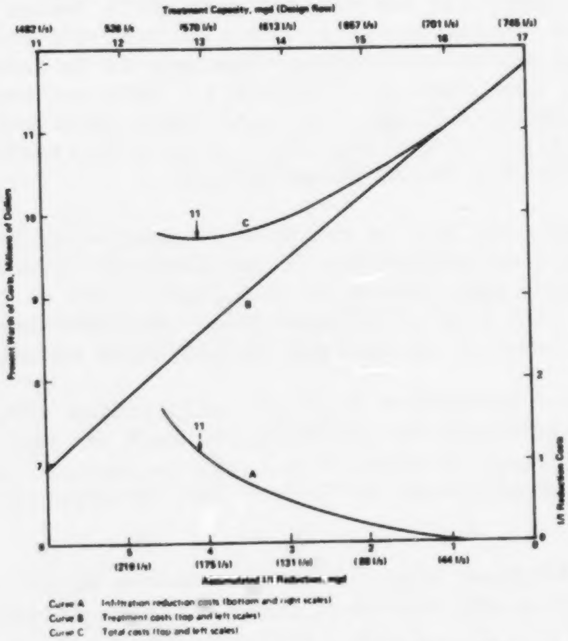
It should be noted that the present worths of net costs for removal of inflows itemized at the bottom of Table 8 are negative, thus indicating



Curve A Infiltration reduction costs (bottom and right scales)
Curve B Treatment costs (top and left scales)
Curve C Total costs (top and left scales)

Note The arrows pointing to Curves A and C indicate the positions of the eleventh ranked infiltration reduction project

Figure 1. Cost-effectiveness solutions for primary and secondary treatment.



Curve A Infiltration reduction costs (bottom and right scales)
Curve B Treatment costs (top and left scales)
Curve C Total costs (top and left scales)

Figure 2. Cost-effectiveness solutions for primary, secondary, and tertiary treatment.

net savings rather than costs. The savings result from the reduction in flood clean-up costs that are attributed to the exclusion of these inflows. As a result, these inflows merit elimination from the collection system without consideration of treatment costs.

No specific consideration has been given thus far in the analysis to the cost of transporting the infiltration and/or inflow to the treatment facilities. Such costs may involve construction and operation of relief sewers and/or pumping stations. These costs do not add to the infiltration reduction costs, but to the treatment costs. To the extent that such costs can be identified for each separate project shown in Tables 7 and 8, they should be tabulated and accumulated in the reverse order of the rankings shown in Table 8. That is, an extra column should be added to Table 8 which identifies the accumulated cost of transporting to the treatment facility the remaining infiltration not removed by the infiltration reduction projects listed through that point in the table. The relationship of accumulated transportation costs to accumulated infiltration reduction costs, and the incorporation of transportation costs in the cost-effectiveness analysis are illustrated in Figure 3.

Note: The curves shown are not derived from the previous numerical analyses and are merely suggestive of their form.

Since the transportation costs add to the treatment costs, it may be desirable to postpone evaluation until rehabilitation projects have been screened for preliminary cost-effectiveness in comparison with treatment costs alone. Any projects not found to be cost-effective in this screening will not be cost-effective when transportation costs are included, unless the remedial action is needed to fulfill a transportation function as well.

The purpose of an infiltration/inflow analysis is to ascertain whether the collection system is likely to be subject to excessive I/I. Excessive I/I is defined as that which is more costly to transport and treat than to exclude from the system. If the analysis identifies the possible existence of excessive I/I, a sewer system evaluation survey must be performed.

Sewer System Evaluation Survey

The sewer system evaluation survey requires a detailed, systematic examination of the collection system to determine the specific location, estimated flow rate, and method and cost of rehabilitation versus the cost of transportation and treatment for each identified source of I/I. The results are summarized in a report that includes, in addition to the information previously described, a justification for each sewer section cleaned and internally inspected, and a proposed rehabilitation program for the sewer system to eliminate all excessive I/I.

For this example, it is assumed that a survey was performed and that the sewer system infiltration data presented in Tables 7 and 8 were confirmed. However, the infiltration was found to be much less persistent than

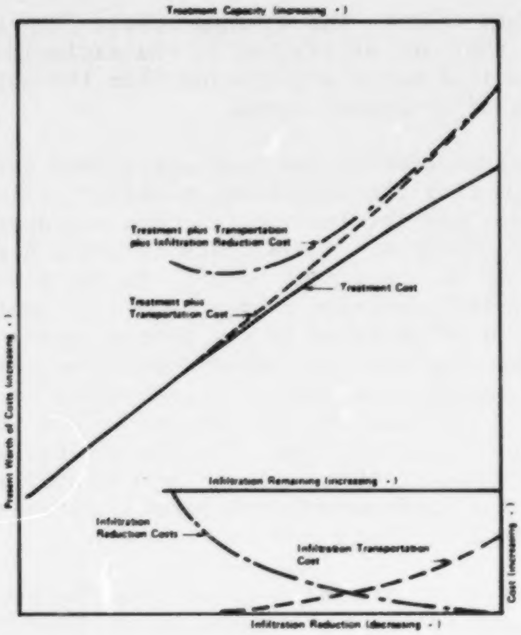


Figure 3. Incorporation of transportation costs in cost-effective analysis.

previously assumed, contributing mainly to the peak flow at the treatment plant. As a consequence, the cost-effectiveness analysis requires that the costs of infiltration reduction be added to those of treatment facilities, expressed in terms of peak flow capacities rather than nominal or design flow capacities. For this example, a peak flow treatment plant capacity of 34 mgd (1,489 l/s) is assumed to be needed if no infiltration is excluded from the collection system.

Since most plants are designed for peak capacities of two to three times their design capacity, the capital and operating costs of the treatment facilities used in this example are those calculated for plants whose design capacities are one-half of the peak capacities shown. Thus, the capital and operating cost for a 30 mgd (1,314 l/s) peak capacity primary and secondary plant are estimated to be $5,938,000 as a present worth (7 percent, 20 years), the same value as shown in Table 7 for a 15 mgd (657 l/s) design flow plant of that type. This procedure is appropriate for capital costs but may overestimate the operating costs properly allocated to the treatment of infiltration.

Since the most cost-effective combination of infiltration reduction and wastewater treatment is determined by the balancing of infiltration reduction costs against the incremental costs associated with the change in plant capacity required to accommodate the infiltration, the approach taken here seems reasonable. In any event, actual costs for construction and operation should be developed on an item-by-item basis wherever possible. Only those costs properly assignable to the treatment of infiltration should be used to determine a cost-effective solution.

The results of the cost-effectiveness analysis are shown in Figure 4. The cost of the sewer system evaluation survey ($646,000) is included in the determination of total costs. Its components and their costs are assumed as:

Physical Survey	$100,000
Rainfall Simulation	120,000
Cleaning 20 percent of System	195,000
TV Inspection	181,000
Analysis	50,000
Total	$646,000

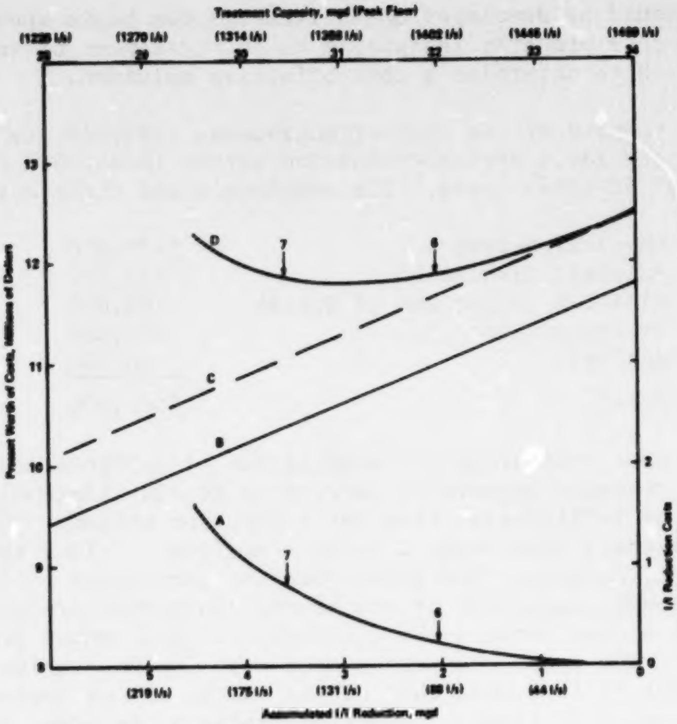
The most cost-effective combination of infiltration reduction and wastewater treatment appears to correspond to the elimination of 3 mgd (131.4 l/s) of infiltration from the collection system. This is the point at which the total cost curve D is at a minimum. Unlike the previous illustrations, however, this point does not correspond to the reductions obtained through completion of any of the individual projects. Rather, it falls almost midway between the sixth and seventh ranked projects. Taken individually, the total cost associated with implementation of the seventh ranked project is less than that of the sixth; and so implementation of the first seven infiltration reduction projects, in order of ranking, provides the most cost-effective combination. It is not likely that this solution could be improved upon by completion of only the first six projects and a portion of the seventh in an effort to reach the minimum point of the curve since the costs would tend to follow a straight line connecting the total costs associated with the sixth and seventh projects rather than following the curve shown.

As was stated previously, the costs of transporting the remaining infiltration of approximately 0.85 mgd (37.2 l/s) to the treatment plant should now be determined and incorporated in the analysis. If no relief sewers or pumping station construction would be required and only incremental pumping costs on existing facilities must be considered, the transportation costs are estimated as follows:

> Assume a total lift of 30 ft (7.9 m), overall efficiency of 65 percent, and energy cost of $0.015 per kilowatt-hour, and a flow of 1.31 cfs (37.2 l/s).
> The power required is calculated from the equation:

$$P = \frac{Q\gamma h}{7.376E} = \frac{(1.31)(62.4)(30)}{(7.376)\ (65)} = 5.11 \text{ kw}$$

where:
P = power, kilowatts
Q = flow, cfs
γ = unit weight of water, 62.4 lbs/ft^3 (1 kg/l)
h = pumping head, ft
E = overall pumping efficiency, %



Curve A: Infiltration reduction costs (bottom and right scales).
Curve B: Treatment costs (top and left scales).
Curve C: Treatment plus survey costs (top and left scales)
Curve D: Total costs (top and left scales).
Note: The arrows pointing to Curves A and D indicate the positions of the sixth and seventh-ranked infiltration reduction projects

Figure 4. Cost-effectiveness solutions for primary, secondary and tertiary treatment based on peak flow capacity.

The energy cost for pumping 0.85 mgd (37.2 l/s) over a period of one year is: (24 hr/day) (5.11 kw) (365 day/year) (0.15¢/kw/hr) = $671/year.

Operation and maintenance costs, taken at 50 percent of the power costs, make the total annual cost ($671) (1.50) = $1,007. The present worth of this annual cost, ($1,007) (10.594) = $10,670. It is obvious that this amount is not large enough to change the cost-effective solution.

USE OF HOUSEHOLD FLOW REDUCTION DEVICES

In recent years, a variety of household flow reduction devices have become commercially available. These devices restrict the flow rate of household plumbing fixtures such as kitchen and lavatory faucets and showers, or otherwise decrease the total amount of water used per cycle in fixtures and appliances such as toilets and washing machines. Descriptions of the devices and their costs and operating characteristics are reported in a number of publications (6,7,8). While these devices were developed primarily as a means for conserving water supplies, they also afford the opportunity for reducing wastewater collection system flows and, thereby, capacity requirements for treatment plants as well. Consequently, the devices merit consideration as a means for accomplishing wastewater flow reductions in the development of wastewater facility plans.

From a water quality viewpoint, the effects of household flow reductions are similar to those of I/I reductions. The principal difference then, between flow reductions accomplished by sewer rehabilitation as contrasted to household flow reducing devices relates to the integrity of the collection system itself. Use of the household devices makes no contribution to the maintenance and/or improvement of the sewer system and may mask its deterioration significantly. No benefits can be claimed with respect to decreases in frequency of street cave-ins and savings in repair costs. The household devices do, however, decrease water consumption and the savings such decreases represent contributes substantially to the overall benefits that may be attributed to them.

Many of the household flow reduction devices are not well suited for installation in existing construction largely because of the installation costs involved. Since a substantial proportion of the collection systems subject to excessive infiltration are old systems, serving existing and often old structures, such devices seem less suitable for incorporation in an I/I analysis.

At lease three techniques afford sufficient ease of installation and low cost to be included in an I/I analysis: dual-flush adapters for toilets, insertion of bricks or other materials in toilet flush tanks, and devices to limit flow in shower heads. Aerators for kitchen and lavatory faucets also involve low cost and ease of installation, but the extent of their use makes the estimation of the attainable flow reductions highly speculative. Both the dual-flush devices and those limiting shower head flows have been limited to only field testing in actual households for periods of about one year. The published results (7, 8,) of these tests provide the primary source of data for the following analyses.

The two types of dual-flush devices tested produced average water savings of 5.42 gal (20.5/1) and 3.28 gal (12.4/1) per person-day, for an overall average of 4.36 gal (16.5/1) per person-day. The cost, not including installation cost, ranged from $4.00 to $14.00 per device.

For these calculations the installed cost is taken to be $10 per device. As reported, the expected service life of the device is 10 years.

For the example community detailed in Table 6:

Total flow reduction, 100,000 persons =
(10^6) (4.36 gal/d [16.5 1/d]) = (0.4 mgd [19.1 1/s])

Initial capital cost =
(28,570 housing units) (1.5 devices/unit [$10/device]) = $428,600

For a service life of 10 years, the present worth of replacement cost =

$$(\$428{,}600)\frac{1}{(1.07)^{10}} = (\$428{,}600)\ (0.5084) \qquad = \$217{,}900$$

Present worth of total capital cost =
($428,600) + ($217,900) = $646,500

Present worth of savings attributable to pumping cleanup =
(0.436) ($53,000) (based on $5,000/yr/mgd [$114/yr/sec])=$ 23,100

Present worth of net costs = ($646,500) - $23,100 = $623,400

$$\text{Net cost per unit flow reduction} = \frac{\$623{,}400}{0.436}$$

$$= (\$832{,}646\ 1/s) = \$1{,}429{,}900/mgd$$

The magnitude of this net cost per unit flow reduction is much greater than any of the values calculated for the inflow reduction projects listed in Table 8. As a result, use of the devices to accomplish flow reductions would not be included in any of the most cost-effective combinations of treatment and flow reduction in the previous examples.

However, if the additional benefits of household flow reductions attributable to reduced costs of water purification and distribution are included, the savings prospects change. The cost of water production and distribution is assumed to be $348/mg ($0.0092/1). This is the wholesale rate charged to a neighboring community by a midwestern city of size comparable to the example community.

Water supply savings = ($348/mgd) (0.436 mgd) (365 days/yr)
= $ 55,380/yr

Present worth (7 percent,20 years) of water supply savings
($55,380) (10.594) = $586,700

If this value is deducted from the present worth of net costs calculated previously, the revised value becomes:

Revised net present worth = ($623,400) - ($586,700) = $ 36,700

$$\text{Revised net cost per unit flow reduction} = \frac{\$36{,}700}{0.436} = \$84{,}174/mgd\ (\$1{,}922\ 1/s)$$

On this basis, the use of dual-flush devices for flow reduction would rank third among the projects listed in Table 8, and would become part of all of the most cost-effective combinations of the previous examples. Since the incremental costs of wastewater treatment, in dollars/unit capacity, increase slowly at about $20,000/mgd ($456 l/s) with decreases in treatment plant capacity, the most cost-effective combination of flow reductions and treatment plant capacities in each of the previous examples would still include all of the infiltration reduction projects of the previous solution, plus the household flow reduction project. Treatment plant capacity would decrease by 0.436 mgd (19 l/s), and total cost would decrease appropriately

Limiting Shower Head Flow

The field tests of limiting shower head flow revealed that a limiting flow rate of about 3.5 gpm (0.22 l/s) produced an average water savings of 0.8 gal/person-day (3.028 l/person-day). Installed costs were reported as equal to the material cost of $8 per device. The service life was reported as 15 years.

For the example community:

Total flow reduction = (0.8 gal/day)(100,000 persons) = 0.08 mgd

Initial capital cost =
(28,500 housing units)(1 device/unit)($8/device) = $228,600

For a 15 year service life the present worth of
replacement cost ($228,600)(0.362) = $ 82,800

Present worth of salvage value =
($228,600)(0.667)(0.2584) = $ 39,400

Net present worth of capital costs =
($228,600) + ($82,800) - ($39,400) = $272,000

Present worth of savings attributable to
pumping and clean up = (0.08)($53,000) = $ 4,200

Water supply savings = ($348/mg)(0.08 mgd)(365 day/yr) = $ 10,200

Present worth of water supply savings =
($10,200)(10.594) = $108,100

Present worth of net costs =
($272,000) - ($4,200) - ($108,000) = $159,700

Cost per mgd reduction = $\frac{(\$159{,}700)}{(0.08)}$ = $1,996,250/mgd=($45,576 l/s)

This cost per mgd of flow reduction is clearly in excess of any reported in Table 8, and so the use of limiting shower head flow would not become part of the most cost-effective combinations of flow reductions and treatment in any of the previous examples. If the value of the water supply savings was doubled, however, the cost per mgd flow reduction would be $645,000/mgd ($14,726 l/s) and use of the device would become part of the most cost-effective combinations of flow reduction and treatment for the conditions represented by Figure 2.

Need for Further Clarification

In the development of the illustrations and examples presented in this section, many questions arose which appear to be unanswered or, at best, incompletely answered. In particular, two issues seem to merit further consideration and study.

The first of the issues relates to the "clear water" characterization of I/I. Is it reasonable to assume that infiltration is completely devoid of suspended and/or dissolved constitutents that might impose increases in the organic and/or solids loadings on treatment processes? If so, what is the effect of "clear water" on treatment performance and on the operating costs of treatment. Arguments can be made in support of either increases or decreases in performance and in operating costs; further exploration of the issue, especially analyses of actual case histories, would be helpful.

The second issue relates to the fate of the I/I excluded from the collection system. Does it give rise to or otherwise magnify other environmental problems in the community? How much of it finds its way to the stormwater collection system? If treatment of stormwater is required of a community, how does this affect the cost-effectiveness analysis with respect to I/I reduction in the sanitary sewer system? Such questions as these remain to be resolved.

Many other issues could be recited, some of which may not have substantial impact when considered on a community-by-community basis, but may be important in the establishment of general policies relating to wastewater management and planning. These issues should be identified and explored if sound and rational policies and procedures for future wastewater management and planning are sought.

SECTION V

ROOT CONTROL PRACTICES

Relationship Between the Root Problem and Infiltration

Public sewers are more than conduits for the collection and transmission of wastewaters from homes, commercial and industrial structures and urban surfaces. They are the 'well springs' of available moisture for plantings with root structures which can reach down to the depth of street lines and building connections to tap this unending source of fluid. The drainage lines which serve as this source of water around the clock and over all seasons are sanitary sewers and combined sewers. Of lesser dependability and significance as an enclosure for root growths are separate storm sewers.

Plants, including trees and shrubs, depend upon moisture obtained from the soil and other sources taken into the sap system by capillary action. Plants fare best when the moisture is available as interstitial fluid, not in the form of water which when it inundates root structures of most plants stunts or rots their growth.

The presence of such interstitial fluid in the soil is not assured at all times because of unpredictable dry periods. The moisture-seeking root growths of trees and shrubs reach out for sources of greater dependability. Sewers which are laid sufficiently close to surface plantings and at shallow enough depths to be reached by root structures provide this dependability.

So great is the need and desire of tree and shrub growths for moisture as well as for anchoring of aboveground growth structures into the surrounding soil, that root growth, diametrically, equals the spread of a tree's branch system. In fact, root spread is not limited by this width factor.

Roots are composed of either tap or fibrous systems. The extent of the system depends on whether the main or tap root persists as the prominent structure or whether it is replaced by numerous secondary shoots or root branches. The main root structure is composed of the central tubular growth, or cortex, and the epidermis from which secondary roots form in hair-line formations. Such water can set up new central systems and their own capillaries. These hair root complexes increase the moisture-absorbing surface of the root system and its spread into areas of potential water and mineral sources. Roots are normally free of pith, beyond the wood or xylem, but the "curtain" of subroot formations is relatively fibrous and tough.

The water-seeking function of the root formation, the ability of a single root strand to become the parent of a new system of hair-like films, and the toughness of the fibrous formations exacerbate the problem of roots in sewer systems. The vaporous atmosphere in sewer lines, together with the potential plant nutrients contained in the sewage flow and in the exuded vapors, attract root intrusions.

Whether roots are the cause or effect of infiltration and exfiltration is academic. Root intrusions and groundwater intrusion or extrusion are a fact of life in sewer system operation and maintenance. If infiltration occurs, groundwater is in contact with the exterior of the pipe. During dry conditions the sewer allows water vapor to be present in the surrounding soil which may trigger root growth into such soil regions.

If groundwater does not surround all or parts of the sewer line during the entire year, defective sewers can produce exfiltration of wastewater into the soil structure. This moisture could readily become the inducement for root growth into the wetted area. Once at this point, the roots seek the source of the vapor - the inside of the sewer lines. In this case, just as in the case of infiltration, root growths enter the sewer barrel and produce the associated operation and maintenance problems.

Differences of opinion exist as to whether roots are the cause or effect of infiltration and exfiltration: do roots find minor defects in sewer lines which do not, in themselves, represent sufficient disunity in pipes to cause either infiltration or exfiltration, and does the proliferation of the root intrusion result in a further opening of the minor opening---which may originally merely produce a moist outer surface on sewer pipe? Or, does infiltration or exfiltration exist through pipeline defects which are large enough to permit the entry of root formations? And will roots, once they intrude through such points of defect, cause rupture of pipe structures or joints because of the growth of "wood" or xylem?

Those who support the belief that roots can produce progressive sewer and joint defects point to the ability of tree roots to split or fracture walls, foundations, and walkways. Whether this vegetative force works in this manner or not, the fact remains that roots do enter sewer lines, and do grow almost explosively in the sewer atmosphere, are not readily discouraged, and do pose a problem. Without question, there is a direct relationship between the conditions surrounding infiltration and root intrusion, whether root growths create greater infiltration or whether the dense root growths can actually fill in pipeline and joint defects and temporarily "seal" leakages.

Another factor which may stimulate the growth of tree and shrub roots into and through the soil surrounding sewer lines is the fact that when lines are laid, they disrupt the virgin composition of the underground. The backfill material, often carefully specified by construction requirements, and though compacted, may provide easier access to root structures than the surrounding indigenous soil. The composition of the pipe soil cushion and the backfill up to the haunch of the pipeline may serve as a "French drain" around the sewer line and provide flowing water or interstitial water which roots seek.

When sewers are laid along easements, trees may be placed along the trench to provide a "fence" between properties, or because this is the easiest place in which to plant.

The basic principle is clear that infiltration and the sewer root problem are interlocked. For this reason a review of root control practices was made a part of this study.

Root intrusion problems do not occur in the presence of minor vegetative or silvicultural growths. Grasses, small shrubs, flowering plants and food, feed and small fiber growths do not produce, nor do they need, far spreading, depth penetrating root structures to support the aboveground growths. The main sources of root formations that can reach and enter sewer lines are trees and large shrubs.

Proximity of such plantings to sewer lines is the key factor in whether their root structures will reach sewer lines, enter them, and produce operation and maintenance problems. This, then, limits the problem to the urban environment and the juxtaposition of tree and shrub plantings and nearby sewer lines. It limits the problem, or at least the intensity of the problem, to urban areas which are more heavily planted and where the plantings are of sufficient age to have produced root growths of dimension and depth to reach sewer lines.

The urban region can be divided into business and commercial areas where tree planting and shrub growths are minimal, and residential sections where street and property beautification has led to heavy growths. Even in business areas recent aesthetic thrusts have produced curbside tree planting, often by the transplanting of partially matured conifer and deciduous forms which already have heavy root balls and which can rapidly spread to seek moisture, nourishment, and anchorage.

Street beautification and lawn aesthetics are the major cause of sewer rooting because they are located near house sewer connections with street and easement sewers. In areas where no restrictions have been imposed on the types of tree plantings and their locations by city ordinances, property owners have often chosen fast-growing species which are known to have greater affinity to moisture sources and to sewer intrusions. Where municipal forestry agencies control tree plantings, they have greater opportunity to stipulate types and locations that are less of a hazard to sewer personnel in making tree planting decisions.

It is obvious that trees and yard shrubs place house connections in greater root jeopardy than street sewers due to location and depth at which house sewers are laid. Trees located along the front or rear of property lines must extend root growths half the width of the street when sanitary sewers are laid at the centerline of the right-of-way. Where sewers are laid on both sides of the street, the distance from tree lines to sewer lines is foreshortened and root problems may be intensified. The use of combined sewers along both curb lines, as is the case in communities where short runs are used to pick up stormwater inlets and catchbasins, results in tree plantings that are located in overhanging position along the sewer lines.

The incident of root intrusion into house laterals was reported more often than for street sewers---a verification that root intrusion rates are in inverse proportion to the distance of the sewer lines from tree and lawn planting. Experience has shown many communities which types of trees are the most troublesome and after-the-fact regulations have been enacted in some cases to bar such so-called nuisance trees in future planting and even order removal of existing stands.

It would be expected that high groundwater conditions might minimize root intrusion into sewers because the "thirst" for underground moisture could be met without drawing on sewer atmospheres and constant immersion in groundwater could produce a rotting or stunting of root hair growth mats. However, evidence of this phenomenon is not clear-cut. Nor is evidence that certain types af soil are more prone to permit deep and widespread root formations than other soils, such as heavy clays vis-a-vis sandy loams. In coastal areas where saline water tends to intrude into groundwater tables, the presence of high chlorides could inhibit profuse root growths.

The relationship between infiltration and root intrusions is best illustrated by the fact that defective joints are the major point of both adverse conditions in sewer systems. The ability of root formations to grow both in mass and in length once they gain a foothold in sewer lines is well known and of concern to sewer maintenance personnel. The proliferation of sewer mats or "lace curtains" in sewers exposes more root surface for the absorption of sewer moisture thus indicating the favorable environment represented by the sewer atmosphere. These long runs of roots can totally clog a sewer barrel, as evidenced by growths removed from lines which have assumed the circumference and diameter of the infested conduits.

It is obvious that roots may tend to enter points of sewer defects - joints or line cracks or breaks - near the top of the pipe or above the side springline of the pipe, rather than at the bottom of the sewer. The upper section of the sewer is where roots are found in sanitary sewers and along the pipe invert in storm sewers.

The propensity of roots to enter at these distinct locations supports the theory that roots are seeking vapor rather than water which always occupies the bottom sector of sanitary sewer lines.

Clogging of lines is the product of two conditions; the dense growths which close off the free flow, and the straining or screening action of root tentacles which are not dense enough to impede flows but become matted with grease, sand, sewage particles such as paper, rags and fecal matter, and storm runoff debris.

All of these conditions are translatable into sewer maintenance problems which have been disclosed during the surveys of root experiences and control measures carried out during the course of this study.

ROOT CONTROL PRACTICES

Since roots go where wastewaters flow, it is essential that root growths be "built out" of sewer systems. This again emphasizes the relationship between infiltration and root infestation problems; if water can get into or out of sewers, roots inevitably will find entry via the same points of defect.

Until existing sewer lines are made tight by rehabilitation, reconstruction or replacement, root growths will occur. The 1970 study by the APWA Research Foundation (9) labelled I/I as "pirates" of sewer system capacities, and "usurpers" of highly important carrying volumes. Root infestations, in a similar manner, rob sewers of their flow-through capabilities and create service failures which are costly and hazardous to the sanitation and conveyance functions of modern sewer systems. If root entry cannot be prevented in sewer lines, the challenge to system operation and maintenance agencies is to conduct comprehensive and thorough maintenance procedures.

Root formations and consequent line clogging and stoppages will occur more frequently in building connection sewers than in street collector sewers. Previous studies have demonstrated that the length of such house lines may equal that of street sewers to which they are tributary, considering the runs of such connection lines on both sides of any sewered street. The smaller diameter of connection lines adds to the potential clogging and actual stoppages of service.

Part of the problem in root formations in house sewers is that once the growth is established in these connections - frequently near the stub connection to the street adjacent to the curb line - these root mats tend to enter the street sewer in search of less restricted growth areas and the uniform vapor atmospheres in the collector sewers.

Where house connection responsibilities are divided between the municipal sewer agency and the private property owner, root problems may involve both entities. Some municipalities maintain connections from the property line to the street sewer, with property owners charged with maintenance from the house to the property line. Other agencies assume no responsibility for stoppages in the entire connection line and still others provide maintenance for the service line for its entire length. Root control measures are influenced by these policies.

The principal root control measure used for house sewers is reaming or cutting of the mats which cause clogging and impedence of service. An entire industry has developed to provide house sewer stoppage corrections, the bulk of which are due to root masses and the build-up of sewage solids and greases caused by the straining action of filamentous growths. The so-called "Roto Rooter" cleaning operations identify the work of the plumber and drain cleaner regardless of the type of scrapper or cutter devices they utilize.

While some property owners use chemical herbicides to inhibit root growth, e.g. as application of copper sulfate crystals periodically into toilets or caustic drain compounds in sinks or other fixtures, the general tendency is not to practice preventive measures. When a stoppage occurs, the afflicted property owner often looks to the municipality for relief. Diagnostic investigations are then initiated by sewer maintenance crews to determine the location of the root infestation and to place responsibility for clearance on the owner or the sewer agency.

Root control in street sewer systems involves what can be called the four practices of build-out . . . block-out . . . clean-out . . . and snuff-out (or kill-off).

o Build-out of root intrusions involves the construction of sewer lines that provide water-tight and root-tight joints, and pipe that is free from imperfections when installed and will not crack, break or deteriorate during service. If a system is infiltration-free it will be root-free. The types of pipe materials and joints now being manufactured are generally capable of being installed to minimize root intrusion at joints.

o Block-out of roots in sewer systems involves the sealing or closure of points of defects in pipe and joints through which roots now intrude and which to the point of this national study, are sources of infiltration. These block-out practices include chemical sealing practices, grouting or repair of points of infiltration and root entry, insertion of internal pipe or tube structures, and actual replacement of sections of sewer lines which are deemed non-sealable or non-corrective by internal lining or which may be more cost-effective than sealing or related methods. The methods, materials and mechanisms used for chemical grouting, other sealing methods, internal lining and pipe replacement are listed and described in the Product and Equipment Guide and the Manual of Practice.

o Clean-out of roots in public sewers involves the tearing or cutting of root formations and their physical removal by means of devices pulled, dragged or rotated through sewer lines from manhole to manhole. The principle involved is the same as that used in the "snaking" or cutting of root clogging material in building sewer connections. The various types of tools for threading clean-out lines through sewers, devices for pulling or propelling root clean-out equipment, and scraping, cutting and dragging root clumps from sewers are described in the Product and Equipment Guide and the Manual of Practice.

Cleaning is a temporary and ineffective means of clearing sewers of root growths. Roots are persistent in finding points of entry into sewer lines. The first root formation is usually fine hair-line growths. When cut, each hair-root can be expected to "twig" and resume growth after the abrading or cutting operations have been completed. In addition, cleaning does not remove all of the root within the sewer. Thus, sewer maintenance forces know the locations of densest root intrusions and they expect the need to return to these areas due to the recurrence of stoppage conditions. Root removal procedures parallel those used for other sewer cleaning purposes such as removal of sludge, sand, grease, debris and other deposited or congealed materials. In general, the same types of cleaning apparatus, with some modifications to handle the tough fibrous root masses, are used for all sewer maintenance purposes.

Root growth may be year-round but the general experience is that roots intrude most heavily in the fall and winter season of general foliage dormancy, except for conifer tree types, and in the spring before leafing occurs. Surprisingly, root growth is less active during the summer season, if general field experience is used as the gauge of the infestation problem.

o The snuff-out of sewer roots involves the use of inhibiting chemicals which attack filamentous growths and disintegrate or decompose the root structure. This procedure is likened to the use of herbicides to eliminate unwanted vegetative growths by above-surface applications. It is more than a trick of semantics to define sewer roots as the "crabgrass of drainage systems." Chemical "snuff-out" may be more than the mere temporary removal of in-sewer growths. The herbicide may infuse the root material and be carried upward a short distance into the main root stem by capillary action. If this occurs the chemical stunts regrowth beyond the time frame that would be affected by the physical cutting or tearing of the root mat from the sewer barrel by means described under "clean-out."

Chemical treatment for root control varies from the simple to the sophisticated. Periodic dumping of dry chemicals into manholes upstream of heavily infested sewers and the solution of this material in the sewage flow during indeterminate time periods can be classified as a simple and generally ineffective procedure. The introduction of root inhibitors into sewers in the form of solutions which are blocked off and permitted to flood or foam sewer lines and, in some circumstances, fill house laterals, have been utilized in the past few years.

Advances in Root Control with Chemicals

Much research has been devoted to what has been referred to here as root control by so-called "snuff-out" methods - chemical herbicide kill - under the direction of plant physiologists, botanists and other scientists not directly involved in the wastewater field. Investigations of herbicidal performance of various types of chemical formulations have been initiated by such research agencies as the Connecticut Agricultural Station and the University of California, using greenhouse and lathhouse screening methods to evaluate kill levels. Such experimental work on various types of root structures of plants has been aimed at determining types of herbicides, strengths of concentrations and methods of application which will inhibit or destroy root growths without producing unwanted kills of the surface plant life itself.

The translation of research plant physiology and biology work into workable methods for controlling root growths in sewer systems has resulted from studies and definitive evaluations of performance at such locations as the County of Sacramento, California.

The Sacramento studies represented intensive examinations and evaluations of many known herbicides (listed in Table 9).

A facet of chemical treatment that is also described in the Product and Equipment Guide and the Manual of Practice involves the addition of herbicidal material to chemical grouting compounds and becomes incorporated in the stiff gels which either create a water seal around defective joints and pipe defects or produce a closure in the joint itself or the pipe crack or fracture. The terminology of "plus" is applied to the sealants which add chemical inhibitors into their formulations. A commonly used material is metham; another is dichlorobenzonitrile. AM 9-plus, and 3M elastometric sealants with a similar chemical root retardant are described in these two volumes of the project report. It is contended that the addition of such chemicals to the sealant materials adds to the ability of the chemical grout to resist the further intrusion of root growths for several years. Literature attributed to the Connecticut Agricultural Experiment Station at Windsor, Connecticut, describes the life and effect of these "plus" chemicals as toxicants to root formations.

Table 9. Herbicides Tested in Root Control Experiments

Common Name	Chemical Name	Trade Name	Formulation
Bensulide	0,0-diisopropyl phosphorodithioate *S*-ester with *N*-(2-mercaptoethyl) = benzenesulfonamide	Prefar	Emulsifiable concentrate
Dichlobenil	2, 6-dichlorobenzonitrile	—	1% emulsion
		Casoron W50	50% wettable powder
Dinoseb	2-*sec*-butyl-4, 6-dinitrophenol	Premerge	Alkanolamine salt
Endothall	7-oxabicyclo (2.2.1) = heptane-2, 3-dicarboxylic acid	Dipotassium endothal	Dipotassium salt
		Hydrothol 191	Cocoamine salt
Metham (SMDC)	sodium methyl=dithiocarbamate	Vapam	Water soluble concentrate
		Vaporooter	Vapam + surfactant
Paraquat	1,1′-dimethyl-4,4 bipyridinium ion	Paraquat	Water soluble concentrate
Trifluralin	*a, a, a,* trifluoro-2, 6-dinitro-*N, N*-dipropyl-*p*-toluidine	Treflan	Emulsifiable concentrate
2, 4-D	(2, 4-dichlorophenoxy) acetic acid	Dow Formula 40	Alkanolamine salts
		Weedone LV4	Butoxyethanol ester
2, 4, 5-T	(2, 4, 5-trichloro = phenoxy) acetic acid	Weedar 2, 4, 5-T	Triethylamine salt
Copper sulfate	copper sulfate $5H_2O$	Bluestone	94.3% pentahydrate
Chlorthiamid	2, 6-dichlorothiobenzamide	Prefix	7.5% granules

This information is included here, not with the intention of presenting adequate details of chemical root control which is available elsewhere in the current literature as well as to some degree in other portions of this report, but to attest to the workability and feasibility of this method of root control on a corrective and preventive basis. There is need for such information to demonstrate to sewer authorities who have either used chemicals ineffectively or who have abstained from utilization of herbicidal treatment "until it has been proven effective," that this method of control merits consideration.

The California studies were under the direction of professional plant physiologists and biologists. Coupled with closed-circuit television inspections of sewer root conditions and actual dig-up of sewer sections, field studies resulted in a rating scale for root kill, ranging from one for no-effect to ten for total kill. Rating of each joint allows follow-up investigation of effectiveness to be made.

Immediate short-term and long-term effects on root growths in sewer lines were determined. From information gained, Sacramento County established its present chemical root control procedures, perhaps the most comprehensive program now in use in the United States. Other noteworthy investigations which have been translated into actual field practices by sewer maintenance agencies have occurred in California at the City of Los Angeles, County of Los Angeles, and at St. Petersburg, Florida.

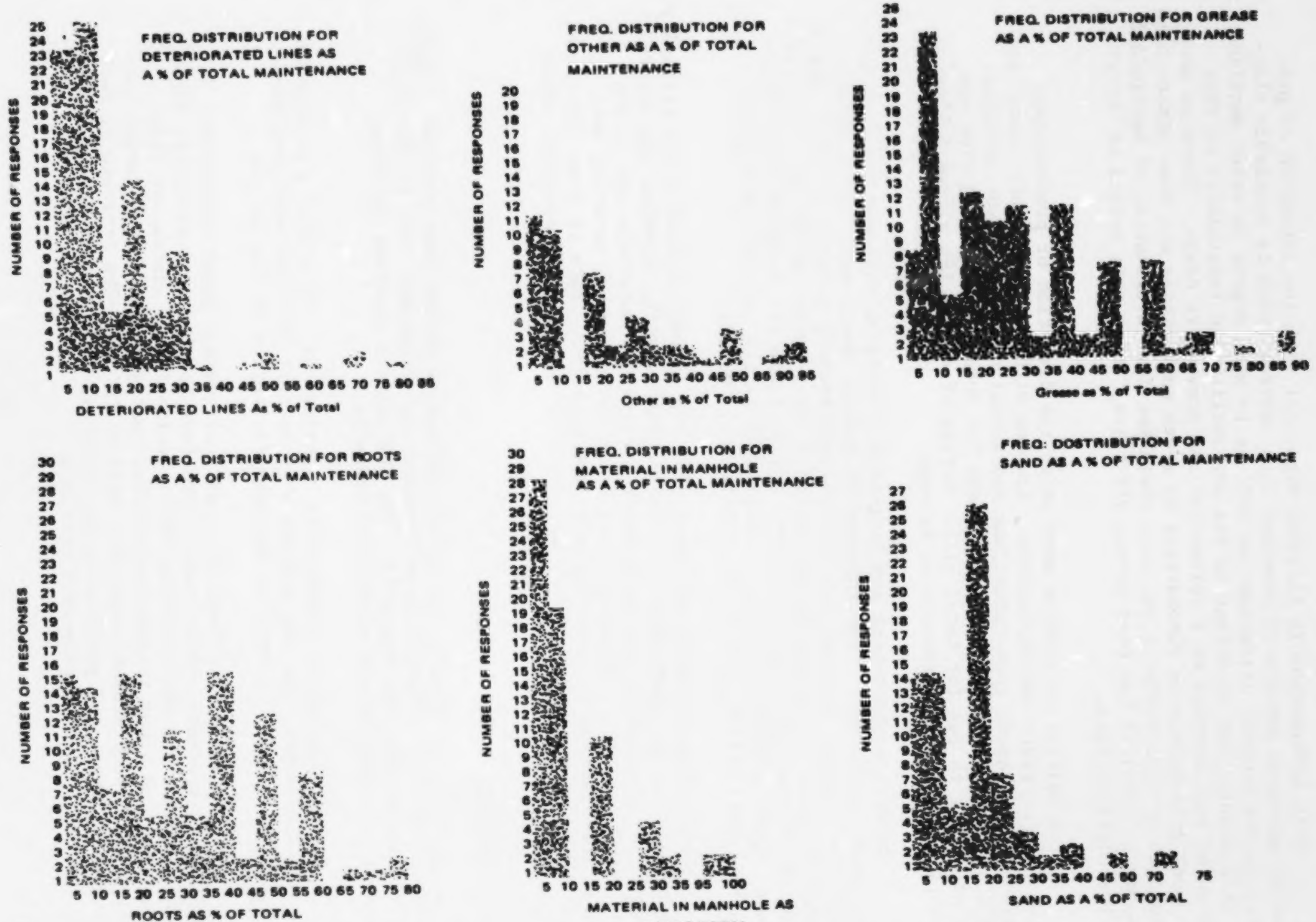
Soaking and foaming have been utilized in root control work, primarily with two herbicidal chemicals - Metham and Dichlobenil, products now incorporated in commercially available sewer application materials and in the major sewer sealants. Long-term root kills are reported, covering both matured root growths in sewer barrels, and fine hair roots in pipe joints and other points of entry before they are actually visible to inspection camera equipment.

The Mail Survey

In order to explore the extent and nature of the root problem, a mail survey of selected community sewer systems was conducted. Out of 402 inquiries 133 sewer agencies responded. The information provided in these responses is evaluated and summarized herewith.

A vast majority of communities reported that roots were a problem in their sewer systems. The few systems with no root problems were geographically dissimilar, not located in any specific region of the nation.

Root intrusion problems are a part of overall sewer maintenance in all community systems. These overall problems involve accumulations, depositions, growths and deteriorating debris which impede wastewater flow. Grease, sand and other intruded materials, root growths, debris dumped into manholes and other related conditions were all cited. The presence of such conditions is presented graphically in Figure 5, with similar data given for other facets of sewer maintenance problems.



Source: 1975 APWA Survey

Figure 5. Reported causes of sewer collection system problems

Figure 5 demonstrates that there is no single cause of the total sewer maintenance problem.

When asked if they conduct root control programs, 83 cities responded in the affirmative. This program in some cities resulted in over 2,000 dig-ups per year due to root intrusion in sewer lines. The highest rate of dig-ups per year was found in the southern half of the United States. This is probably attributable to the warmer climate which induces greater tree growth. The stoppages per year because of roots, in all cases, were higher than the number of dig-ups per year.

The surveys disclosed that sanitary sewer house laterals are the source of most problems with root intrusion. Root intrusion also was a major problem in the combined sewer house lateral. Table 10 interprets this problem in terms of type of sewer systems.

Table 10. Relative Importance of Root Problem by Types of Sewer

(Number of Yes Responses)

	Sanitary	Combined	Storm
Collector	88	42	37
Interceptor	14	5	10
House Lateral	102	48	

Source: 1975 APWA Survey

Thus, it can be concluded that roots are more often a problem in the smaller, and often shallower lines, with the house lateral a key weak point.

In the course of this survey information was obtained on use of chemicals: foam chemical grout sealing with herbicide additives and non-herbicide grouting, and direct dumping of chemicals into manholes. A tabulation of the responses to this question is given in Table 11.

Table 11. Nature of Chemical Maintenance Program for Root Control

Chemicals	Number of Yes Responses
Foam	18
Dump in Manhole	44
Sealant	8

Source: 1975 APWA Survey

The general extent of chemical control has therefore been to dump liquid or dry chemicals in the manhole. Such procedures are often used to attempt to open blockages in the line.

The use of rodding and sewer ball equipment, along with other methods was explored. Rodding of sewers was the predominant method reported.

A total of 93 out of 133 cities reported that they are satisfied with their maintenance techniques. The remaining were unhappy or dissatisfied with their procedures.

The mail survey included an inquiry concerning the size of collector sewers affected by root intrusion. The majority of the respondents indicated that the sizes of the sewer most affected by root intrusion are in the 8 to 12 in. (20 to 30 cm) range (Table 12). This data again indicates the relative importance of the root problems in small diameter pipe, where the presence of I/I flows may have a major effect upon the available carrying capacity.

Table 12. Size of Collector Sewers Affected by Root Intrusion

Sewer size (in)	(cm)	System length (mi)	(km)	Length affected (mi)	(km)	Percent of total length affected
6	15	4,161	6,935	1,935	3,225	13.9
8-12	20-30	33,003	55,005	11,323	18,872	81.5
15-24	38-61	5,828	9,713	489	814	3.5
Over 24	61	3,113	5,190	144	240	1.0

Source: 1975 APWA Study

Officials were asked what type of trees or shrubs produce the greatest amount of root problems in their area. The majority responded that willows caused the most problems, followed by elms, maples, oaks, poplars, and pines. Shrubs such as hedges, lilacs and privet hedge plantings also were reported to cause root intrusion problems. Certain trees that are indigenous to specific climatic areas were reported to be root-intrusion problems but the types listed were reported for all parts of the country.

The points of root intrusion were identified as joints, house laterals, wye connections to collectors, and line breaks, in relative order as indicated in Table 13.

The importance of joints as a point of root intrusion can be attributed to early pipe joint design such as use of mortar and jute joints, use of early bituminous joint compounds, defective workmanship and inspections and inadequate replacement programs for sewers. Survey data indicated that current compression-type-O-ring joints are serving to minimize infiltration and root intrusion.

Table 13. Point of Intrusion by Roots

	Mean	Median
Joints	54.6	60
House Laterals	38.0	20
Y on Collector	22.1	15
Other	17.2	15
Breaks	12.9	5

Source: 1975 APWA Survey

Because of the importance of house laterals as a source of root intrusion, the survey explored the question of who is responsible for maintenance of the various lines. Sixty-nine of the 133 responding agencies inspected the "Y" portion of the service connection, while 42 out of 133 respondents reported that they assumed responsibility for the house lateral to the property line. Only a small portion, three out of 133, took responsibility for the house lateral to the building line.

The use of sewer sealants by municipalities has become a more general practice. The municipalities that have used sewer sealants reported that root intrusion has been reduced. Subsequent root intrusions have had minimal effect on chemically sealed joints. Some communities have modified their sealing methods as a result of roots.

Many agencies reported that root intrusions have caused cracking, opening or crushing of joints and pipe but a lesser number attributed infiltration to such root actions. No clearly defined data were available as to whether root growths preceded or followed infiltration conditions.

Relationship between the depth of groundwater and the extent of root intrusion was explored; 46 cities reported that roots were not a problem in shallow ground-areas while 61 stated that there was no such correlation.

Responding to the question of whether soil types had any relationship to the extent of root intrusion, replies were evenly divided on the subject: 44 correlated soil types with root growth while 45 did not.

The survey indicated the wide extent of the infiltration problem; 106 reported that infiltration did occur while only 21 said that it was not a problem.

The findings of the mail survey lead to three major conclusions:

- Root intrusion is just one of many sewer maintenance problems. It is not the total cause of system malfunctions. It is a combination of a host of problems and of the need for line cleaning and rehabilitation. It follows from this that a complete sewer maintenance program is needed, based on principles of preventive servicing before system failures and consequent drainage functions are affected.

- The data base of the surveys was not complete in all respects. Certain desirable data were not available because field experience in some systems is too limited to permit a complete evaluation at this time.
- Infiltration is a major problem in a great majority of the systems surveyed. This condition is caused by deteriorated lines, root intrusion and lack of sewer system rehabilitation, repair and replacement. The problem of infiltration must be given increased attention. The USEPA "Needs Survey, 1974" estimated that almost $5.3 billion will be needed nationwide to correct the infiltration and inflow problem.

It was apparent that some of the sewer maintenance - root control - infiltration relationships had never been evaluated by officials before this survey was instituted. The mail survey findings were augmented by onsite investigations of 21 selected community systems.

ON-SITE SURVEYS OF SEWER ROOTS PROBLEMS AND CONTROL

On the basis of the findings of the I/I study, information obtained from a national mail survey questionnaire evaluation, and other guidance means, 22 communities were selected for more intensive investigations of root problems and control practices. On-site, in-depth investigations were carried out in the selected systems by Research Foundation representatives with experience in this phase of sewer operation and maintenance.

This section of the report summarizes the on-site findings for the investigated systems and evaluates and interprets the interview data from those systems which had relevant data and experiences.

The community sewer systems investigated were chosen to represent a cross section of sewer root problems and approaches. They covered large and small systems in various parts of the United States; those with well developed sewer maintenance and root control programs and those with less effective practices; those which have used chemical control methods for root-kill and those which have not utilized these means and have avowed objections to their use; those with major root problems and those with only minor growth-clogging conditions; those well versed and aware of the importance of root control and those where root removal is considered only an unimportant part of the sewer cleaning operation; those with highly sophisticated sewer maintenance equipment and those less prepared to keep their systems at peak transmission capabilities.

The community systems covered by the on-site survey program were:

The City of Los Angeles, California; Sacramento County, California; Los Angeles County, California; City and County of Denver, Colorado; Charlotte-Mecklenburg County, North Carolina; Chesapeake, Virginia; Buffalo Sewer District, New York; Shreveport, Louisiana; Dallas, Texas; Fort Worth, Texas; Austin, Texas; Metropolitan St. Louis Sewer District, Missouri; North Little Rock, Arkansas; Champaign, Illinois; Madison, Wisconsin; Yakima, Washington; Seattle, Washington; Southwest Suburban Sewer District, Seattle, Washington.

The questionnaire responses served as the springboard for the on-site surveys. Therefore, a brief summary of each system is given prior to the pertinent comments from its field interview.

Charlotte-Mecklenburg County, North Carolina

Overview - A system of separate sanitary sewers operated and maintained by a utility department serves a population of 300,000 in the City of Charlotte, and urbanized parts of the county. Forty percent of sewer maintenance required for root contol - one-half of the total mileage of 1,082 mi (1,803 km) of collectors and 200 mi (333 km) of interceptor sewer - is subject to root intrusion. Willows, maples, oaks, elms and poplars all produce root problems. Cleaning must be repeated frequently because this procedure does not remove all growths and regrowth occurs.

On-site comments - This system is an example of sewer conditions which show a minimum relationship between infiltration and root intrusion. Root problems affect about half of the city-county system of collector and interceptor lines but the groundwater table is relatively low in the service area and most sewers are laid in the dry. Eighty-five percent of root intrusions occur at defective joints, only three percent at pipe breaks and a very minor amount at house laterals.

- Sewer construction practices have induced root entry at joints. From 1927 to 1958, joints in vitrified clay sewers were made up of jute and cement grout; from 1958 to 1961, bitumastic poured joints were used; since 1961, O-ring type compression joints have been installed and tight joints have resulted.

- Ten percent of rooting difficulties has occurred at the physical connections between house sewers and street sewers, again due to poor construction in older practice. In older connections, plumbers often broke out a hole in the street sewer and inserted the end of the house lateral, with a cement collar. Present practice is for the city-county agency to drill with a diamond cutter and to make the connection with an ABS plastic sewer tap saddle or with a cast aluminum or cast iron saddle arrangement. Tight connections have resulted. Connections for building sewers over 4 in. (10 cm) size must be made via a manhole. Plumbers or owners are refused permission to make connections; city work is billed. No pre-set wyes are provided in street sewer construction. Root intrusion has been minimized in new construction.

o Root control is achieved by routine sewer maintenance methods, with use of so-called conventional tools and equipment, including five rodding machines and hydraulic jetting units. Root removal is done on both routine maintenance schedules and emergency complaints. Officials consider a preventive maintenance schedule of once-yearly de-rooting effective, but the present average check of root-infested sewer sections is on an 18-month schedule.

o Officials consider root removal procedures as overly expensive for the results accomplished because of regrowth of mat formations. No chemical treatment has been tried; the county agency is waiting for proof of chemical effectiveness and safety. It will consider chemical control if the current USEPA-APWA study recommends it.

o Roots were reported to enter sewers in the upper quadrant of the pipe; little root problem occurs in lines laid deeper than 8 ft (2.4 m). Roots at the sewer crown are not cut off cleanly by cutting tools and hydra-flushers. Regrowth is so rapid in some root-infested lines that bi-monthly cleaning would be desirable.

o The clay-like soils in the Charlotte area do not inhibit root growth. The opinion was expressed that root growths in joints and pipe defect areas can produce cracking or progressive opening of points of entry.

o Roots are more dominant in older areas of the service territory where sewer joints are poorer and where tree growths are more mature than in newer development areas. Willows are the worst offenders, with privet hedge affecting building laterals. Maples, poplars, elms, all types of oaks, and junipers, are found to be the most troublesome types of trees. No control over street plantings was reported.

o The field coverage of root removal operations in a sewer section that had not been cleaned for some six months, disclosed no root clogging even though this was in an area with heavy tree overhang where sewer officials had assumed they could show the investigator heavy infestation conditions.

Chesapeake, Virginia

Overview - Community of 100,000 population, with only 50,000 sewered. System consists of 300 mi (500 km) of public sewers. Of 400 stoppages per year due to roots, most are located in house laterals. No chemical treatment has been attempted. System experiences heavy infiltration due to high groundwater levels. Rooting in laterals is due to elms, maples, gums and quick myrtles located close to shallow house lines.

On-site comments - This sewer system experiences high infiltration but low root intrusion; it represents a paradox in this respect because sewer defects do not result in heavy rooting problems. The explanation, as offered by sewer officials, is that groundwater is very high, sewers usually inundated, and root growths impeded from seeking sewer entry in search of either vapor or water. The groundwater table is affected by tides in the low-lying coastal area and intrusion of saline water into the groundwater is reported to discourage root growths.

The major root problem occurs in house laterals, particularly at connections to street sewers. Few basements are used in the city and the laterals are laid at shallow depths - from a maximum of 42 in. (1.06 m) deep to a minimum of only 12 in. (30.5 cm). Roots which enter building lines tend to grow out into the street sewers, causing stoppages at the junction point and in short stretches of collectors at these locations.

Chesapeake is one of a series of satellite communities around the Norfolk, Virginia metro area. The Public Utility Department owns and operates the sanitary sewers and the Public Works Department has responsibility for storm sewers. The Hampton Roads Sanitation Commission, created by a state act, provides interceptor and treatment services for Chesapeake and other communities.

High infiltration is the concern of the commission which has prompted the city and other communities to correct this condition. The commission is in the unusual position of threatening to increase the sewer service charges to cover the cost of high flows caused by infiltration if corrective actions are not taken; a recent increase in service rates was imposed.

o The city assumes responsibility for building sewers from the street sewer to the property line and, therefore, becomes involved in the root problems in these lines. Building laterals are provided with clean-out fixtures at the property line, which serve as entry points for root cutting tools. It becomes a problem to check all lines to ascertain whether stoppages exist in the section between the building line and the property line.

o Of the 400 root stoppages per year, most are located in these lines; about 50 dig-ups per year are required for stoppages which cannot be cleared by rodding or flushing. Close proximity of tree and shrub growths adds to root intrusions in house sewers.

o Street sewer root growths are usually limited to lines under 8 ft (2.4 m) deep. The soil is sandy and mud-structured, producing what is known locally as "running sand." Infiltration carries this soil into sewer lines, resulting in street washouts and pavement failures.

o Root control work has been limited to only about 5 mi (8.3 km) of sewers per year, usually on a complaint basis, but some preventative maintenance work is scheduled in areas where root infestation is known to be high.

o Old sewers were laid with mortar joints which failed readily; later, bitumastic joints were poured; and more recently, compression-type O-ring joints have been used, with reduced infiltration. Inflow is not a problem because of the absence of basement and foundation drains and roof leader connections.

o Roots are reported to be more troublesome during dry seasons, thus confirming the relationship between groundwater levels and the minimal root conditions in street sewers.

o The city makes house sewer connections to street sewers, either with wye fixtures and special water-tight saddle devices or plastic seals, or by diamond-drilled openings, properly connected and made water and root-tight.

o While the computed frequency of root cleaning in the sewer system is many years between servicing incidents, those street sewers where rooting is more troublesome average one cleaning per 18 months. So-called conventional root removal procedures, rodding and high-pressure flooding, have been employed. No chemicals have been used. If auger-type tools do not clear lines, a scrapper known as "grandma" is pulled through the line in the form of a wiper. Dig-ups are the final answer if underground methods fail.

o TV inspection of sewers has not been undertaken. No sewer sealing by chemical grouting has been tried, and attempts to obtain funds for sewer leakage control have failed. The city has advised the Hampton Roads agency that it will progressively replace lines in poor condition, will install new lines to meet the commission's standard infiltration of 350 gal/in-diam/mi/day (0.33 m^3/cm-diam/km/day), and will make street sewer connections without plumber service but will require guarantees of tightness of all plumber's work for one-year periods.

o As funds permit, concrete lines which failed by sulfating in tidal groundwater are being replaced as part of the rehabilitation program.

o Trees which cause root problems primarily in house connections are classified as: elms (the most troublesome), maples, gum trees and a type known locally as "quick myrtles."

o Inflow can occur in manholes which are low-lying and subject to inundation during storms. However, manhole covers are fitted with internal "dust covers" which are set under the street cover and become relatively watertight due to deposits of "dust" or debris that sift into the space between the regular cover and the under-cover.

o It is again stated that infiltration is high in street sewers and root intrusions relatively low. This must not be interpreted to mean that no collector sewer root problems exist. They do, but in lesser degree than could be expected from the condition of the city's sewer lines. The relationship between high groundwater, saline water intrusion into the fresh groundwater, and low root intrusion remains the highlight of this on-site survey.

Buffalo Sewer Authority, New York

Overview: A multi-community system serving the city of Buffalo and areas in Erie County. The population of 460,000 is served by both separate and combined sewers. The length of the separate sewers is 320 mi (533 km), and of combined sewers 485 mi (808 km). Fifty percent of the sewer maintenance problems are due to root growths. Roots are also a problem in storm sewers.

On-site Comments: The Buffalo Sewer Authority, created by state legislative action in 1935, operates the sewer system for the city of Buffalo but the bulk of the outlying sewer districts in the authority service area maintain their own systems. The authority provides interceptor and treatment service to the entire jurisdictional area. Buffalo is sewered primarily by combined sewers, in many cases as old as 100 years. Newer outlying areas are served by separate sanitary sewers but interceptors are combined in nature and overflows contribute to the pollution in international waters which is the concern of the International Joint Commission representing the United States and Canada.

The old sewers are subject to infiltration and heavy root intrusion. About half of the lines are under the groundwater table at least during part of the year. The rest of the system is laid high-and-dry; it is possible that exfiltration occurs in such sewers. It was reported that 80 percent of the city's sewer system is subject to root intrusion. Root control is practiced on both a preventive basis, as time is available, and on complaint of sewer stoppages. While root intrusion problems were reported to cover this major percentage of the city's system, the miles of lines cleaned per year average only 40 to 50 mi (67 to 84 km); this would represent servicing of the total system only once every six years but this schedule is ameliorated by greater frequency of cleaning in areas where root difficulties are known and anticipated.

Root control measures have been conventional rather than innovative, except for the use of chemicals which are periodically dumped into manholes in affected areas, reportedly with good results. No sophisticated flooding, foaming or vapor treatments have been used. Root removal has been by rodding and use of routine cutting or pulling tools. The first high-pressure flusher purchased by the authority was delivered during the survey.

o The relationship between overall sewer maintenance and root control in the Buffalo system is portrayed by the fact that 50 percent of the maintenance problem is due to root growths - 30 percent to grease accumulations and 20 percent to sand and debris accumulations. Industrial wastes were reported to cause some sewer clogging difficulties.

o Collector sewers and house laterals are involved in both separate and combined sewer maintenance problems, as well as in storm sewers. No interceptor root problems were reported.

o Roots enter sewer lines that are relatively deep - 50 percent of the problem occurring in sewer lines 8 to 12 ft (2.4 to 3.7 m) deep. Even sewers of greater depth are subject to root intrusions. Thirty percent of the root problem is due to intrusions into poor joints and an equal amount via sewer line breaks. House laterals, as usual, are the points of 40 percent of root entry, with most of the intrusion occurring at the connection of the house line to the street line.

o Root intrusions into street lines are induced by the fact that combined sewers are laid near the curb line on both sides of the street, adjacent to tree lines. These plantings are made by the City Forestry Department but there is no evidence that the authority is consulted about the types of trees that will produce less root growth problems.

o Authority officials believe that root intrusions produce joint deterioration and further breakage of line defects but there is no evidence on whether the openings into sewers existed prior to or after the root intrusions occur.

o Root intrusion and infiltration are commensurate with age of sewers. Three-quarters of the city's sewers are over 50 years old; 60 percent were built prior to 1910 and only 7.8 percent installed since 1941. Trunks built prior to 1930 were of brick, stone or segmented block. Street sewers are mostly vitrified clay, with earlier joints made of mortar which were subject to openings for potential root intrusion and infiltration. Newer lines have been built with compression joints, and root troubles and infiltration have been minimized.

o Sewer rodding is carried out with flat slat sticks strapped together with disposable wire clips. The flexible and relatively unbreakable slats which float in the sewer lines, are used to thread cleaning cables through sewers. In many areas sewers are located under sidewalks, making them vulnerable to tree root intrusions.

o Tree root problems in Buffalo are attributable to maples, poplars and elms.

Shreveport, Louisiana

Overview: This city of 225,000 is served by a 675 mi (1,125 km) sanitary sewer system. Concrete and vitrified clay lines have been installed over the past 30 to 40 years, with grouted joints. Root stoppages average 300 per year in the 25 percent of the sewer system which is subject to root intrusion. About 15 percent of the 158 mi (263 km) of affected sewers is cleaned annually, only five percent of the system requires maintenance per year because of rooting conditions, indicating that root conditions are not a major problem in the city. Some parts of the system require as much as weekly root control servicing. Root clogging is limited to street collectors and house laterals, with no difficulties experienced in interceptor lines. Most of rooting occurs at joints - 60 percent of all problems - with 25 percent at pipe breaks and 15 percent at wye connections between house sewers and street lines. Root intrusion is greatest where groundwater table is low and sewers are laid at shallow depths in the sandy loam soil.

On-site Comments: The Shreveport separate sanitary sewer system experiences root intrusion problems, primarily due to poor joint construction in lines 30 to 50 years old. House lateral rooting represents 15 percent of the overall problem, located primarily at wye connections to street sewers. Root intrusion is equated with low groundwater levels in the system and shallow sewers. Chemical treatment has been tried with unsatisfactory results.

- Root intrusion is minor into storm sewer lines. In sanitary sewers root problems are located at points of line defects but the system personnel do not believe that roots produce their own points of entry; in other words, roots find existing openings rather than producing them.

- An ordinance enacted in June, 1975 requires property owners to correct conditions in house laterals which produce system back-ups and malfunctions.

Dallas, Texas

Overview: A population of approximately 900,000 is served by about 2,500 mi (4,167 km) of separate sanitary sewers and 500 mi (833 km) of interceptor lines. Roots are a major problem, judging from the 2,000 dig-ups per year, 6,000 stoppages involving root growth and 600 mi (1,000 km) of sewers cleaned per year. Forty percent of the sewer system was reported to be affected by root intrusions, with a quarter of the system requiring annual attention. Root intrusion in house laterals is "high." Shallow sewers, under 5 ft (1.5 m) deep, are markedly affected by roots. Sewers deeper than 8 ft (2.4 m) are seldom affected. Joints are the major point of root entry; 30 percent of the total root problem occurs at wye connections to collector sewers.

On-site Comments: Root growths are a problem and the investigation provided an opportunity to obtain the views of wastewater collection personnel on causes and effects of this condition.

- This system is constructed in soils with exceptionally low groundwater levels. Root growths are induced by search for moisture; where water tables are higher, root growth is impeded.

- Roots are not the cause of infiltration; they are the effect. In fact, roots are thought to seal existing sewer line openings and thus reduce infiltration. When roots enter through line breaks or joints their growth is limited by the flow in the sewer because roots cannot grow into the flow. Thus roots proliferate where flow rates do not cause sewer surcharges. Pipe size has less influence on root growths than flow lines.

- Older sewer lines were of 4 to 8 in. (10 to 20 cm) sizes; newer lines are being laid with 12 in. (30.5 cm) pipe, thus providing greater capacity with lower flow lines.

o Roots constitute 85 percent of the cause of sewer system stoppages and dig-ups. Sewer lines fail due to improper backfill, pipe fatigue and other contractor practices. Grease accumulations reduce flow-through capacity and thus enhance root growths in the less-filled flow lines.

o Chemical treatment for root control is viewed with favor. Slip lining of defective sewers with polyethylene pipe and heat fusion of pipe are used successfully to correct infiltration and consequent root problems.

o Chemical grouting of defective sewers is practiced, such as in concrete pipe which has failed due to corrosion. TV inspection is used to confirm sewer conditions and benefits of sealing and other corrective measures.

o In arid areas, disturbed ground resulting from sewer construction acts as a drain channel and creates infiltration. Root intrusions are greater in clay and chalk-limestone soils than in sandy soils.

o House laterals are the cause of root intrusion, as well as of infiltration. Defective laterals are checked by the city and the property owner can be required to make repairs, subject to fines or shut-off of water service. The city maintains lateral responsibility up to the property line at which point a clean-out is installed at a cost of approximately $25 to the property owner. This clean-out is used for clearing root growths and determining the location and responsibility of stoppages. Officials believe that house lateral infiltration and root intrusions cannot be solved by conventional control measures instituted in the street sewer system.

Austin, Texas

Overview: The separate sanitary sewers in this system, 1,200 mi (2,000 km) of collectors and interceptors serving 300,000 population is not seriously affected overall by root problems. Forty percent of sewer maintenance is caused by grease accumulations, 30 percent by deteriorated lines, 20 percent by stoppages caused by material dumped into manholes, and only 10 percent by root growths, 6 percent of which requires annual maintenance.

On-site Comments: Only six percent of the separate sanitary sewer system requires annual maintenance for root control. The main source of root intrusion in the system was reported to be house laterals.

o A recent ordinance requires all house lateral construction to be hydrostatically tested for joint and other defects with correction of such defects due within 60 days of notification, subject to discontinuance of water service.

o City officials estimate that 75 to 90 percent of the sewer system's infiltration and root problems are caused by defective laterals.

o The investigator gained the impression that roots cause a majority of the problems although the proportion was not quantifiable.

o Opposition was expressed to chemical control of roots because of the danger to ground vegetation and protests from environmental groups.

o No rehabilitated lines have required repairs since 1955-1958, due to use of 12 to 25 in. (30.5 to 63 cm) of crushed gravel backfill around pipe, combined with the use of plastic pipe and expansion joints.

St. Louis Metropolitan Sewer District, Missouri

Overview: This metro system serves 900,000 population with separate sanitary sewers and 700,000 population with combined sewers. Root growths are a problem in the 2,300 mi (3,833 km) of sanitary and 1,200 mi (2,000 km) of combined collectors but no root problems are reported in interceptors. About 180 mi (300 km) of sewers are cleaned annually for root intrusion control, or less than 10 percent of the 60 percent of the metro system affected by roots. Only four percent of the sewer system was reported to require annual maintenance for root clearance, with the maximum cleaning frequency of one year. Chemical treatment of roots has been tried, with unsatisfactory results admittedly due to inability to apply properly because of back-ups into basements. Roots represent 26 percent of the causes for sewer maintenance; the greatest cause (42 percent) is rocks, rags and paper. Bucket machine cleaning produces positive results but is reported to be too slow. Sewers laid at depths of 8 to 12 ft (2.4 to 3.7 m) are reported to be affected by root intrusions. Chemical grouting has reduced root growths. "Plus" herbicides have been added to chemical grout to improve root control. Willows, elms and sycamore trees were reported to produce the major root problem.

On-site Comments: The District, while in control of the metro system, does not have control of house services which represent about 10 percent of the root intrusion problem. Eighty percent of system infiltration is thought to occur from house services.

Officials believe that roots produce infiltration only when joint bells are broken. When root entry is made through simple joint openings, the belief is that exfiltration rather than infiltration will occur. The extent to which root diameter growth would result in infiltration was not given but growth is relatively slow.

Chemical control is practiced, but with some skepticism. Several trees and shrubs have been killed by root control chemicals and the District has had to replace damaged vegetation. The main problem with chemical treatment has been the need to block off house service lines when flooding is practiced.

Metro is now experimenting with grouting with herbicide additives because grout without additives has not stopped root intrusion.

o Cutting roots with a bucket with a blade is effective for small roots but the District is seeking a more permanent method of root control.

North Little Rock, Arkansas

Overview: This smaller system, serving a population of 60,000 with separate sanitary sewers, 400 mi (667 km) of collectors and 50 mi (83 km) of interceptors, has a root growth problem affecting 40 percent of the collectors. Thirty percent of the sewer maintenance work is caused by root intrusions, with other causes not exceeding 20 percent each, thus making root conditions the main cause of stoppages. Fifty stoppages per year constitute the maintenance load, with 30 mi (50 km) of sewers cleaned annually. Ten percent of the system requires root control maintenance per year, with a three-year maximum frequency for root removal. Seven different brands of chemicals have been tried for root control, methods of application unspecified, with unfavorable results. Ninety-five percent of sewers of 6 in. (15 cm) size are affected by roots and 90 percent of the 300 mi (500 km) of 8 to 12 in. (20 to 30.5 cm sewers are so affected; only minor percentages of 15 to 24 in. (38 to 61 cm) sewers and two percent of over 24 in. (61 cm) lines are root infested. The bulk of root intrusions occur at joints with house laterals involved in 20 percent of the problem. Grouting of leaking lines has been carried out, with a slight reduction in root growths; root intrusions have not affected chemically sealed joints. Roots were reported to cause pipe bell cracking and subsequent infiltration. Types of trees or shrubs causing root problems were reported to be willows, oaks and shrubbery.

On-site Comments: The on-site survey helped to clarify the data contained in the mail survey questionnaire.

o Seventy to 90 percent of infiltration in the system - and consequent root intrusion - occurs in house laterals which the city does not maintain. Current requirements specify use of cast iron service lines but earlier practice allowed fiber and concrete pipe. Plastic service lines have been tried but officials could not control the quality of workmanship.

o A rise in river levels for navigation purposes by a Corps of Engineers project resulted in higher groundwater levels and an increase in infiltration. Other cities in the area have filed claims against the Corps for similar conditions.

o Chemical control of roots has been relatively unsatisfactory.

o House services and wye connections are the responsibility of property owners.

Champaign, Illinois

Overview: Fifty percent of the sewer maintenance problem in the 300 mi (500 km) system serving the 60,000 population of Champaign, Illinois, results from root intrusion. The other major cause of sewer stoppages is heavy grease accumulations. One hundred stoppages per year involve root growths, with only five dig-ups required to augment the mechanical and chemical control measures which are practiced "year round." Root intrusions occur in the separate sanitary sewer lines, with roots reported in separate storm sewers as well. Chemical treatment, by means of herbicide materials dumped into manholes, was reported to kill bottom root formations and to make mechanical cleaning with bucket machines and jet units more effective. Eighty percent of sewers of 8 to 12 in. (20 to 30.5 cm) size are affected by roots as well as 60 percent of sizes from 15 to 24 in. (38 to 61 cm). Sewers laid at depths of 1 to 5 ft (0.3 to 1.5 m) and of 5 to 8 ft (1.5 to 2.4 m) are most markedly rooted, 40 percent each. Eighty five percent of root intrusions occur at joints, 10 percent at wye connections in house lateral lines and only five percent at sewer line breaks. Roots were reported to cause sewer bells to fail and induce infiltration.

On-site Comments: The on-site survey report provided little additional information.

o Personnel of the sewer agency were not certain whether house laterals are contributors of significant infiltration and root intrusions.

o Chemical control is minimally practiced, due possibly to the city's experience with killing of surface trees and shrubs.

o No plans have been made to require property owners to make repairs of defective house laterals.

Milwaukee, Wisconsin

Overview: This city of 700,000 population is served by 765 mi (1,275 km) of sanitary sewers and 555 mi (925 km) of combined sewers. The city has a root problem and a maintenance program. Chemical treatment by Vapom has been tried, with reportedly unfavorable results, because the Department of Public Works could not introduce chemical properly. Dig-ups for root control are not required to augment rodding and jet root cutter equipment. Only 25 sewer stoppages per year are directly attributed to root infestation, with the overall maintenance program involving 160 mi (267 km) per year. Twenty percent of the separate sanitary sewers is root-affected and root problems are not reported in the combined sewer system. The greatest root troubles occur in sewer lines of 8 to 12 in. (20 to 30.5 cm). Eighty-five percent of the 1,450 mi (2,416 km) of this size range is affected by root conditions. Ninety percent of root intrusions enter sewer lines of 5 to 8 ft (1.5 to 2.4 m) depth. Joints are the major source of root entry accounting for 50 percent, with 30 percent at sewer breaks and 20 percent through house laterals, which are also the source of a part of the infiltration problem in the system. Only elms were reported to cause root troubles.

On-site Comments: The survey provided confirmatory data as well as augmentation of information on sewer cleaning and root control practices.

o Four basic types of equipment are used for sewer maintenance, including root control: hydraulic jetting equipment, sewer rodding units, sewer ball units and bucket machines and combinations of these methods. A study made of cleaning techniques in 1974 showed that none of the methods removed all or even substantial amounts of root growths.

o Rodder cleaning, followed by jetting, was better than rodder alone. Use of a root cutter and the jet nozzle gave better results than the jet nozzle alone. Jet cleaning improved flow conditions, possibly by removing greases and debris but jet nozzles did not remove roots effectively. Rodding does not remove grease accumulations effectively.

o The city maintains carefully scheduled preventive maintenance programs which have reduced sewer stoppages from 160 per year in the 1960s to under 60 per year in 1974. About 20 percent of stoppages occur in combined sewers despite their relatively large sizes, with blockages due more to debris than to root growths.

o Jets do an adequate job on light root growths. Cutting tools may get hung up on bad joints and damage lines when used in conjunction with jets. Rodding machines are used where root growths are heavy, with buckets called into play under extreme root conditions. The value of jetting is attested to by the recent purchase of a third machine and the planned elimination of one bucket machine crew.

o Previous maintenance schedules were based on emergency calls; today's schedules stress preventive cleaning.

o Elm trees are the major cause of rooting. An epidemic of Dutch elm disease has thinned out these trees and they are being replaced gradually with less troublesome types. The most active growth periods are spring and fall and cleaning schedules are planned to meet these peak root conditions. Heavy rooted areas are serviced on a semi-annual basis. Roots seldom intrude into sewers via gasketed joints.

o Roots enter sewers at the upper quadrant of mortar joints. No cases of bell breakage due to root growths were reported.

o No program of chemical root control is in effect. A test of foam application was made some three years ago, with little success, possibly due to improper or inadequate application methods. Evidences of foam in downstream manholes from the point of application were not detected; the test, though not conclusive of failure, discouraged further use of chemical control at the time.

Madison, Wisconsin

Overview: The 500 mi (833 km) separate sanitary sewer system which serves a population of 162,000 has a root problem which represents 50 percent of the overall sewer maintenance program. As in other communities, grease accumulations are reported by Madison sewer officials to cause a major sewer clogging threat, 30 percent of total maintenance needs. Stoppages amount to 600 per year, 200 in street sewers and 400 in the collector lines and laterals. Thirty percent of the system's mileage requires annual root cleaning but some sections of the system require cleaning four times a year. Two hundred twelve mi (353 km) of sewer are root-cleaned annually. Sewer sizes affected range from 6 to 12 in. (15 to 30.5 cm) with the shallower sewers most subject to root intrusions. Seventy percent of stoppages involve sewers under 8 ft (2.4 m) deep. The city does not assume responsibility for house laterals from the building line to the street line, however, wye connections are the responsibility of the city. Forty nine percent of root entries occur at street sewer joints and an equal percentage in house laterals. Elms, ash, oaks and some poplar trees are root-inducers. Roots were reported to cause crushing of joints but this condition was not reported to produce infiltration points.

On-site Comments: The on-site survey provided further information on sewer maintenance, root control and internal grouting of defective sewers to overcome infiltration.

o Sewer back-up complaints total 700 to 800 per year, with two-thirds due to house lateral stoppages, thus indicating that the major source of root infestation is in house connection lines.

o The city clears house laterals only on request and charges for the service. Three rodding crews and two hydraulic jet crews handle 15 percent of the affected sewers quarterly and the remainder are serviced twice annually. The rest of the street sewers are cleaned as time permits.

o Roots enter the upper half of sewer joints, seeking moist air rather than water. Shallow sewers are more affected than deeper lines. Root growths are especially troublesome during dry years. Willow trees cause the greatest root problems but elm tree roots have been known to grow in sewers at least one year after the tree is cut down.

o A test of chemical control about ten years ago failed because the herbicide could not be held in the line long enough.

o Madison owns its own TV inspection equipment and examines all new construction for infiltration above the allowable 200 gals/in-diam/mi/day (0.19/m^3/cm-diam/km/day) as well as for check-up on maintenance work. The equipment is not used for chemical grouting; recent contracts for grouting cost $23,000 for 133 joints, or $188 per joint. Reduction in flow to the treatment plant fully compensated the city for these costs. City TV work costs $0.22/ft ($0.73/m) with precleaning costs of $0.17/ft ($0.56/m).

Yakima, Washington

Overview: The 198 mi (330 km) separate sanitary sewer system which serves 47,000 residents experiences root intrusion problems but overall sewer maintenance involves only 20 percent for root control, as compared to 65 percent for grease removal. Forty-five stoppages per year are attributed to root growths, with eight dig-ups required in cases where regular cleaning does not clear the lines. One-hundred-twelve mi (187 km) of line are cleaned for root control annually but only 18 percent of the city system is subject to root problems. Some sections of the system are cleaned three or more times annually, with such maintenance work limited to the 18 percent of the mileage subject to root intrusions. Small size sewers are more affected than sewers from 15 in. (38 cm) to over 24 in. (61 cm). The bulk of root intrusion occurs in lines laid at a depth of 5 to 8 ft (1.5 to 2.4 m). Joints made of concrete and mastic prior to 1960 are the source of 50 percent of the root problem. Forty percent of the problem is experienced in house laterals.

While only 18 percent of the system is root-affected, some sections are cleaned three or more times per year. Chemicals have been used with unsatisfactory results; mechanical root removal is deemed the most effective means of keeping lines functioning. The major points of intrusion are street sewer joints and house laterals; the city maintains no authority over house connections. The less the groundwater, the greater the root problem. Cement mortar and mastic joints were used prior to 1960; rubber joints are now used for asbestos-cement concrete and plastic sewers.

On-site Comments: One-half of the sewer system is laid in streets and alleys, with the rest located in easements. Easement lines are subject to unusual root intrusions, such as growths from an asparagus field which plugged a four-foot-deep sewer. About one-third of sewers are laid below groundwater levels at least for a portion of the year.

o About 5 mi (8.3 km) of the most heavily infested sewers get special root control attention, ranging from weekly, or bi-weekly to quarterly cleaning, including grease removal which produces 65 percent of the overall maintenance problem. Rodding and jetting procedures are used, with rodding applied for normal root conditions. Heavy roots which cannot be removed by routine means are cut with a locally designed saw-like cutting tool. This heavy tool has been used to cut off protruding house laterals without damaging the lines. Two-man crews are used for both rodding and jetting operations.

o The city has purchased its own TV inspection unit but it is not equipped for internal grouting. Its function is to check new construction for infiltration and existing lines for effectiveness of maintenance.

o The city does not accept responsibility for house laterals which account for 75 percent of stoppages.

o Roots from troublesome trees, such as cottonwoods, sugar maples, willows, weeping birches and even fruit trees tend to enter lines at the lower quadrant of joints, rather than the upper portion. Some thumb-size roots are more difficult to cut.

o Chemical treatment has been spasmodic and poorly controlled, possibly explaining the unsatisfactory results of such materials. Caustic soda, introduced into the soil around a root-infested line, apparently entered the sewer and corrected clogging without affecting nearby trees. No plans for chemical treatment were reported.

o Rooting can occur at any time of the year, rather than only seasonally as reported in other community systems.

Denver, Colorado

Overview: Of the 1,200,000 population of Denver, 1,100,000 are served by 1,200 mi (2,000 km) of separate sanitary sewers and 200 mi (333 km) of interceptors. Ten miles (167 km) of collector combined sewers serve only 100,000 people. Root intrusions are a problem in both street sewers and house laterals but they pose no problem in combined sewers or separate storm sewers. Dig-ups are not required to augment routine sewer maintenance procedures. Only 12 stoppages due to rooting are experienced per year but 300 mi (500 km) of sewer lines are cleaned annually for root prevention. Maximum frequency of cleaning is once yearly in the 30 to 35 percent of the sewer system subject to root intrusions. Ninety percent of root problems occur at joints and 10 percent in house laterals. The bulk (50 percent) of root intrusions occur in lines laid at depths of 1 to 5 ft (0.3 to 1.5 m) with an additional 20 percent in 5 to 8 ft (1.5 to 2.4 m) deep lines. Fifty percent of 8 to 12 in. (20 to 30.5 cm) sewers are affected by roots, with only 5 percent affecting lines of 15 to 24 in. (38 to 61 cm) depth and over 24 in. (61 cm) depth. Chinese elms were reported to be the most troublesome type of trees in root-infested areas.

On-site Comments: Approximately 300 mi (500 km) of sewers are checked for root growths per year. Root intrusions constitute 25 percent of the total maintenance problem.

o While the mail survey indicated that roots are most troublesome in shallower lines, the majority of the city system is laid at depths of 9 to 12 ft (2.7 to 3.7 m) because of the predominance of basement construction in residential areas.

o A carefully scheduled preventive maintenance program is used by the city's four maintenance district crews, each equipped with a TV sealing unit operated by a four-man crew. Prior to the scheduled program 60 back-ups per month were experienced. The preventive program has reduced stoppages to one or two a week. All reports of stoppages are followed up with TV inspections to determine the presence of roots or other impeding materials and the success of the cleaning operations after corrective measures have been taken.

o The entire system is flushed and inspected once yearly; rodding and jet cleaning averages once over two and a half years; some areas are serviced on a 30-day, 60-day and 90-day schedule for grease removal - the greatest cause of sewer stoppages; when crews cannot clear the line with a hydrocleaner, a tag line is left on the job and a TV inspection is requested, with final cleaning followed by another inspection.

o In 1975 the city could rod or jet at a cost of \$0.05/ft (\$0.17/m). Five truck-mounted flexible rodding units, each with a two-man crew, are in service; a similar number of hydrocleaners are used. Prior to 1965, crews used hand rods, at which time Denver made a study of the operations of other cities and modified its procedures.

o The city uses the 1 to 9 root infestation grading system established at Sacramento County to record the intensity of root growths.

- The city carries out a continuing sewer sealing program. If a TV inspection shows joint offsets, root intrusion, radial breaks, poor joints or other defects, these points are sealed. Sealing specifications are rigidly established for time of grouting and setting of AM-9. From five to six joints per 100 yds (90 m) of sewer length need sealing under the city's criteria and 2 to 6 gal (7.6 to 22.7 l) of sealant are used per joint.

- Chemical root treatment has not been used. Copper sulfate has been used with AM-9 for root herbicidal effect during the past five years that sealing has been used.

- The city maintains control over inflow connections.

Seattle, Washington

Overview: The combined sewer and separate sanitary sewer system of Seattle, serving a total population of 523,000, are affected by root growths but stoppages are minimal, 10 per year, and dig-ups are not required to augment the Sewer Utility's manual and chemical root control procedures. The city is generally served by combined sewers, 1,018 mi (1,697 km) of line, as compared with 493 mi (822 km) of separate sanitary sewers. Fifty three percent of sewer maintenance involves root growths, with 35 percent of clogging attributable to sand deposits and 10 percent due to grease accumulation. Some parts of the system require root removal every three months but only 20 percent of the overall system requires root maintenance annually. Chemicals such as DPO, XL222 San Fax, copper sulfate and sewer solvent have been used. The opinion was expressed that results were unsatisfactory because the materials were effective for grease but not for roots. Root problems involve street sewers, interceptors and house laterals, with no problems reported in storm sewer lines. Cleaning operations involve use of rodding equipment, high-pressure jet units and cable drag bucket machines. Sixty percent of root intrusions occur at joints and 20 percent at house laterals. Most sewers are 8 to 24 in. (20 to 61 cm) in size and these sizes are most affected by root intrusions. Shallow sewers are most predominantly intruded, with 50 percent of the problem in lines under 5 ft (1.5 m) deep. Wye connections to street sewers are the location of 15 percent of the root intrusion problem. Most troublesome tree types are willows, poplars, maples, cottonwoods, laurels.

On-site Comments: Four rodding crews, two hydraulic jet crews, one TV survey crew and one inspection crew are used, over and above the repair crews. An additional TV unit has been purchased, with video taping equipment but no grouting equipment is owned.

- Twenty to 25 percent of the sewer system has been color-coded on a map for guidance of sewer maintenance schedules. The trouble areas are thus designated. Root cutting is performed in larger sewers with buckets, and with rodding machines and straight cutting blades in smaller lines. Attempts to cut roots with a hydraulic jet fitted with a saw attachment were unsuccessful and this method is not being used. Maximum attention for root clearing is four times per year.

o Sewer blockages are the cause of major concern because the city pays claims for the resulting damages. The city has paid such claims on at least six occasions due to root stoppages from trees in city streets.

o With annual rainfall of 35 in. (89 cm) roots apparently enter sewers seeking food rather than moisture. Root entry at joints occurs near the top of the pipe. In one case, roots substantially filled a 21 in. (53 cm) pipe in four years. Willows and poplars are the most troublesome. Roots never intrude through gasket joints.

o Chemical treatment for root control is viewed with disfavor because of the steep grades of sewers which would produce unwanted back-ups of chemicals into basements, and because the cold temperature of city water and wastewater flows would impede such treatment. Dumping of copper sulfate into manholes, with holding in the line, proved unsuccessful. Other trials with blocked-off sewers, using unspecified chemicals and caustics, proved indeterminate.

Sacramento County, California

Overview: Sacramento was one of the first sewer agencies to use Vaporooter for most control purposes. Studies of application methods and results have been conducted with the University of California at Davis and numerous reports have been prepared and published, covering various types of herbicides and combinations thereof.

o County sewers are relatively small, mostly from 6 to 12 in. (15 to 30.5 cm) in size. Root problems predominate in the 6 to 8 in. (15 to 20 cm) lines, seldom in lines larger than 12 in. (30.5 cm). Root intrusions are heaviest in lines laid at depths of 7 to 15 ft (2.1 to 4.6 m) which constitute 70 percent of the system's mileage.

o Root intrusions occur primarily in lines that are at least 25 years old because they were laid with joints which are considered undesirable under today's standards. Asphalt fiber sewers have failed as house laterals. Ten percent of root intrusions occur at connection points between house laterals and street sewers; 10 percent enter poor joints in the house laterals; the rest intrude through defective joints in street collectors. Root intrusion in storm sewers is usually at joints which are merely butted together without a joint material: here roots are "woody" in nature and enter the bottom of the line. In sanitary sewers roots are more hair-like and intrude into the sides and top of the line, but dig-ups have disclosed that root growths generally encircle the total pipe circumference.

o On-site Comments: While the county's chemical control program is of major significance and was the main thrust of the on-site survey, routine sewer maintenance is standard practice in the system. Four ball-crews work year-round; a high-pressure hydrocleaner crew of two men is used mostly for grease removal, a major maintenance problem. Two coil-rodding crews work throughout the year, and one TV inspection crew of three men carries out inspections of root conditions and other surveillance work. These crews clean

600 mi (1,000 km) of sewers per year, varying in frequency of service from yearly to every six years depending on root and other intrusion and deposition problems in specific areas of the overall system. An effective preventive maintenance program is guided by good records and scheduling.

o The highly publicized herbicide treatment program was initiated in 1969. One crew of three men works during the summer season when root growth is reported to be most pronounced, as compared with other climates where spring and fall seasons are considered the periods of prolific root growth. The crew has treated 200 mi (333 km) of sewers at a rate of 50 mi (83 km) per year, over and above the program of treating house laterals with chemical foam. A two-year re-treatment cycle is used in the most troublesome sewer sections.

o In order to interpret the degree of root intrusion into sewers and the condition of roots after chemical treatment, a grading system has been adopted. It involves rating root densities from 1 to 9 in terms of standard internal photographs in the hands of TV evaluators. Reinspection of treated lines shows a kill of 50 to 75 percent. A progressive reduction in root densities occurs with continued treatment as compared to an increase in root growths in untreated lines.

o The sections of sewers being chemically treated are located, primarily, in rear easements where property owners utilize the softer backfill trench area for planting shrubs to serve as backyard fences. The backfill material tends to encourage the growth of tree and shrub roots, as compared to the hardpan nature of the native soil.

o Herbicide treatment in collector lines is carried out by plugging a downstream manhole, flooding the upstream section with herbicide, allowing the flooding to remain for one hour, unplugging the downstream line, plugging a manhole further downstream and allowing the herbicide waters to stand in the succeeding section for an hour. Each batch is used in four successive sections and the same crew can have four separate batches working simultaneously.

o House laterals are plugged at the property line and foamed with herbicide, using a portable unit. Twelve to 18 house laterals can be treated per day. The property owners are not informed of the chemical treatment of laterals or street sewers in order to prevent any fears or protests.

o Strict safety measures are invoked to prevent injury to crews or damage to surface vegetation. During the entire program, only one tree has been partially affected and one grape vine was temporarily stunted. No crew difficulties were reported. Crews are given full indoctrination on chemical handling procedures and they are clothed with clean uniforms and protective footwear. Aprons and respirators are provided to protect against contact with the chemicals and the breathing of fumes. Complete records are maintained of sewer sections treated, chemical usage and other pertinent facts. Approximately $26,000 was spent on chemicals in 1974.

Southwest Suburban Sewer District, Seattle, Washington

Overview: The oldest parts of the district sewer system are 30 years old, although most of the system was installed in the mid-1950s. Sewer depths range from 3 to 20 ft (0.9 to 6 m); concrete pipe with mortar joints was laid prior to 1956 and compression jacket joints are now standard practice. Sewers are subject to root intrusion. The district installs house laterals from the street sewer to the right-of-way line and plumbers extend the laterals to the property, often with poor joints. Much of the root problem originates in house laterals because property owners plant shrubs along the right-of-way in close proximity to the house sewers, providing easy entry for roots. Roots then run longitudinally along the house lateral and into the collector sewers via the wye connections. Services have been dug up and found to be full of roots.

On-site Comments: Two distinct types of roots cause troubles in the district: those that enter sewers through the lower quadrant of joints and grow longitudinally along the bottom of the sewer, such as poplars and willows; and those like the honey locust, that enter all parts of the joint and form a ring effect in the pipe but seldom extend downstream more than a minimal distance from the point of entry.

o Power rodders equipped with a three-prong cutting tool are used to cut the ring-type roots. Six stoppages are experienced per year, mostly stemming from root entry into house laterals which enter the street sewers. Sewer sections with root problems are cleaned every six months.

o Control of roots with dry chemicals has been tried on several occasions, by adding materials into upstream manholes and allowing the plugged line to stand full of wastewater for varying time periods; with a 60-minute holding time considered optimum. Dye has been used as a tracer to show the presence of the herbicide chemical. Hair roots are killed in the sewer and exfiltered chemical solutions have been known to kill roots outside of the pipe. Root growths have been killed for upwards of five years.

o Copper sulfate treatment has been used by placing the chemical in a plastic bag hung in a manhole in contact with flowing wastewater. Crystals have been replaced, as needed, over a period of several months. Growths have been impeded for three years with no detrimental effect experienced at the treatment plant.

o No ongoing chemical control program is presently in effect. A ruling by an attorney representing the District has stated that the agency is not responsible for damage to trees growing on private property if they are damaged by chemical control measures.

Los Angeles County, California

Overview: The Department of Public Works maintains 3,500 mi (5,833 km) of collector sewers, with interceptor sewers operated by the County Sanitary District. Over 90 percent of the system has 8 in. (20 cm) sewers with 90 percent installed since 1945. Groundwater is low and sewers laid at depths of 7 to 9 ft (2.1 to 2.7 m) are not subject to infiltration.

On-site Comments: Roots in desert areas will go to any depth to enter sewers, with elms, palms, tamaracks, oleanders and pepper trees producing the greatest root intrusion problems. Roots affect sewers laid prior to 1964.

o Routine maintenance for grease removal, the greatest problem, and for root control, involves the use of hydraulic cleaner crews, rodding crews and an inspection crew which televises 300 to 400 mi (500 to 633 km) of sewers per year. In 1974 cost of sewer maintenance was $2.50 per residence served.

o A county-wide crew of three to four men is used for chemical control which was instituted in 1970 using Vapom experimentally. Early findings showed that minor regrowth was experienced. Flooding was found inadvisable because of the terrain conditions. Foaming is now used in plugged sewer sections. A 200 gal (756 l) mix tank on a truck is used to make up batches of the chemical for foam application.

o Employee safety measures were evaluated, including use of hoods, cannister masks, full face shields and taped cuffs and coveralls. Crew members do not enter manholes. At the present rate of treatment it will take two and a half years to cover the whole system. The same crew works on rat and roach control when not applying root chemicals.

City of Los Angeles, California

On-site Comments: Root intrusions are present in 20 percent of the system's 6,000 mi (10,000 km) of sanitary sewers and 1,200 mi (2,000 km) of combined sewers, including hillside lots, rear yard easements and streets. Sewers are often shallow and have been affected by earth movement during seismic incidents.

o Groundwater levels are low and most sewers are laid in-the-dry. Minor inflow conditions exist but apparently infiltration is not a general problem. Roots are a problem but grease accumulations are the primary cause of sewer stoppages; about 300 grease stoppages are recorded per year.

o Mechanical rodding has been the accepted method of sewer maintenance but recent budget reductions have resulted in the use of hand rodding crews. Each of eight service districts has one hydrocleaner crew and one inspection crew which handles partial stoppages. A TV inspection crew is available and a city-wide bucket machine crew handles major stoppages.

o A herbicide treatment program with Vaporooter was initiated in 1974. Some 50 mi (83 km) of sewers were treated from October through March, as contrasted with the Sacramento summer program. One three-man crew is used.

o The initial program involved sewer flooding, paralleling the Sacramento program, with one-hour retention of the herbicide in only one sewer section at a time. A one-percent solution was used for flooding which was made difficult by steep grades in the sewers. Preliminary findings showed herbicide treatment will control roots for a period of one to ten years, with an average period of five years. Treated sections have less than 10 percent regrowth of roots. Root problems are not found in interceptor lines or storm drains.

o Foaming has replaced flooding because of greater control of operations and apparently less hazard involved. The on-site report referred to a few accidents occurring during flooding and to five accidents involving foam getting into houses. Flooding involved the dumping of chemicals into manholes by hand and then filling the line with a fire hose.

o Contrary to Sacramento practice, property owners are notified that foaming will take place. Men enter manholes rather than working at the surface; the county does not supply clothing or other protective devices. For foaming, a five-percent solution is used. An experimental run with a 10-percent solution high-pressure spray required greater safety control and other precautions which were considered drawbacks.

o Chemical expenditures amounted to $8,000 in 1975. If funds are available, $80,000 per year will be expended on the program, with two full-time crews.

o There has been little acceptance by the district crews of the technique of chemical treatment and little change has been made in the manual-mechanical maintenance procedures.

o Copper sulfate treatment of roots was attempted several years ago, with no tangible benefits.

St. Petersburg, Florida

On-site Comments: The St. Petersburg sewer system is laid, primarily, under the groundwater table and has been subject to heavy infiltration. This condition is being corrected by continuing TV inspections, sewer sealing and repair procedures. Root intrusions are extremely heavy in shallow lines. Dig-ups are very common, 1,200 per year, and stoppages due to root growths are equally high, 1,500 annually. Roots represent 50 percent of sewer maintenance problems, with deteriorated lines and sand deposits responsible for 20 percent each; grease accumulations, which are high in other systems, represent only five percent of maintenance problems. Thirty mi (50 km) of sewers are cleaned annually for root removal but 60 percent of the overall system of 800 mi (1,333 km) of collectors and 100 mi (167 km) of interceptors were reported as subject to root intrusion. One-half of the root problems are located in street sewer joints and half in house lateral growths usually located at the first joint between the property line and the street connection wye, which is the closest to hedge row trees. Chemical control with Vaporooter Plus, Sanifoam, has produced results that varied from 0 to 100 percent effective. A qualified applicator is required to gain the most effectiveness from the chemical control. Only five percent of the system is reported to require yearly cleaning, despite the apparent concentration of the root problem. "Punk" trees and Australian pipe trees are the major root causers but Vitex, Brazilian pepper, Jacaranda and Turks Cap are listed as troublesome. Roots cause joint failures and consequent infiltration.

SUMMARY

The excerpts from the individual survey reports are intended to add further dimension to the types of problems and solutions to root control. The thrust of the excerpts has been to screen out the points which add to the consensus of root problems and solutions or, where significant, demonstrate differences in procedures indigenous to variances in local conditions.

The agencies which were judged to have the most comprehensive root control programs also appeared to have excellent overall preventative maintenance programs.

Mechanical cleaning offers a positive initial result but appears to make root growth more of a problem over the long run. The work done by the city of Milwaukee provides an excellent guide as to the capability of various methods of mechanical cleaning.

Daily attempts at chemical control of roots were generally unsuccessful as they involved placing chemicals in the manhole and letting the flow carry the chemicals along the sewer. The use of the Vaporooter family of herbicides appears to be the only generally acceptable method of chemical control. Flooding as practiced by Sacramento County is not generally feasible in other areas. Foam application as practiced by Los Angeles County and St. Petersburg appears to offer an effective method.

The safety of Vaporooter to both employees and above-ground plant life appears to be acceptable when used with recommended safety precautions. Although St. Petersburg was the only agency found to use licensed herbicidal applicators transferred from the Parks Department, use of personnel with such training should enhance the safety of a program.

Chemical control with Vaporooter is not 100 percent effective, but repeated applications over several years approaches this limit. No other method of control approaches the effectiveness found in the four major agencies using Vaporooter.

SECTION VI

TIDE AND BACKWATER GATES

Previous studies (10) and the initial APWA questionnaire for the present study identified problems with tide and backwater flow gates as a source of inflow into systems utilizing such devices.

A survey and field visits were made in order to obtain additional information. The firm of C. E. Maguire was retained to analyze the available data and give an engineering review to the design problem.

For the purpose of the study, a tide gate, known also as a flap gate, or backwater gate, is as defined in the 1969 APWA Glossary of Water and Wastewater Control Engineering:

> Tide Gate: A gate with a flap suspended from a free-swinging horizontal hinge, normally placed at the end of a conduit discharging into a body of water having a fluctuating surface elevation. The gate is usually closed because of external hydraulic pressure, but will open when the internal head is sufficient to overcome the external pressure, the weight of the flap, and the friction of the hinge.

Note that a tide gate that conforms to this definition is "self-acting;" that is, energy to actuate the gate comes directly from the water systems in contact with the gate. Note, also, that the term tide gate is used, even though the gate may be locally referred to by another name. Other arrangements, designed to achieve the same result (i.e., allow flow in one direction, block it in the other) amount to four percent of all gates reported. Sluice gates, fabric dams, etc., are used, but these arrangements are not examined in depth in this mail survey.

The kind of tide gate found to be in use throughout the U.S. and Canada consists of a movable plate or disc, pivoted at the top end, hanging against a slightly sloping opening so that gravity holds the gate shut in the absence of a hydraulic head that can cause the gate to open. Large gates 4 ft (12 m) and larger are often of timber, with corrosion-resistant fittings. Gates are used to protect systems from frequent or extraordinary high water conditions and are usually taken for granted. Their effectiveness and economy is generally good and depends largely on the maintenance given them. Only nine percent were reported as being installed at or with mechanical regulators.

Users are 80 to 90 percent satisfied with tide gates. Fouling and sticking cause about 60 percent of malfunctions, with an average annual maintenance expense per gate of $194. The annual labor required is 23 man hours per gate.

The survey indicated that engineering standards for design and application are available from many manufacturers, and that, like all other waste treatment equipment, a certain amount of maintenance cannot be avoided.

Tide Gate Applications

The APWA survey elicited replies from 55 communities which used some 1,300 gates. Nine percent of the installations were at mechanical regulator locations, 62 percent protected sewerage systems from reverse flow, 25 percent protected pump stations and treatment plants, and four percent protected open streams. In other words, all tide gates are used to allow outflow in one direction and preserve the system from inflow in the other. Figure 6 shows the evolution for the need for tide gates.

An older application, now rare, used tide gates to lift water so that it could be used to produce power. In Boston, for example, a system of two ponds, two sets of tide gates and a water wheel were used to drive a mill. Inflow gates on one pond kept it full from high tide, while outflow gates on the second pond kept it empty by discharging to low tide. The system was in use until 1866 (11).

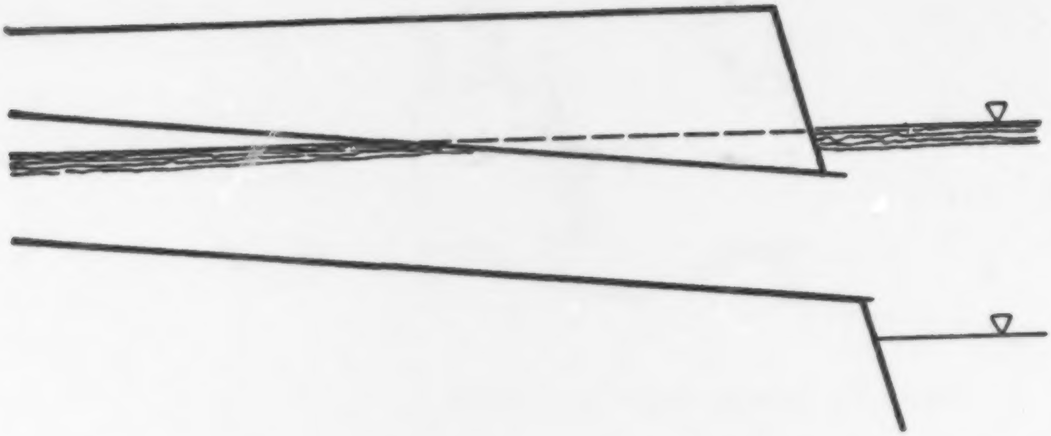
The prevention of reverse flow in a sewer system is commonly accomplished by use of check valves in small systems and backwater, flood or tide gates in larger systems.

Backflow prevention devices include check valves, self-acting tide or flap gates, and power actuated gates used for backflow prevention. Of the larger, self-acting variety, three general types have been commonly used:

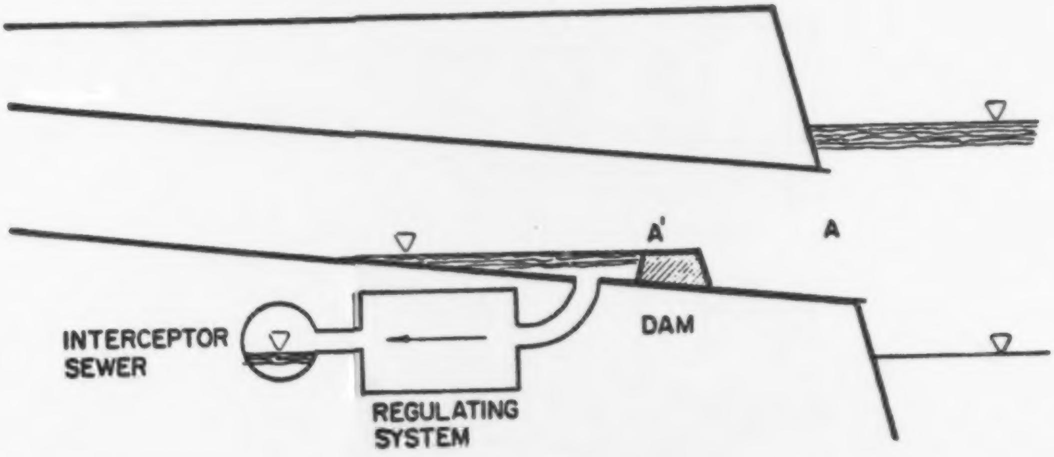
- The side-pivoted tide gate, now obsolete
- The flap gate, with horizontal pivot above a swinging flat plate or disc, and
- The flexible flap type occasionally used for gates less than 12 in. (20.5 cm) diameter.

The common flap gate is manufactured in three common forms: as a solid plate of cast iron or steel, as a thin hollow pontoon (usually of welded steel), or as a timber gate (see Figures 7-12). The powered gate can be of many types, the sluice gate and the newer pneumatic are examples. Figure 13 shows a recent installation of a pneumatic device.

Users in 57 communities reported 88 percent (1,156 gates) were of the flap type, the remainder (156) being power-actuated or miscellaneous.



Original storm drain or combined sewer without reverse flow protection.


A'
A
DAM
INTERCEPTOR SEWER
REGULATING SYSTEM

Modified sewer system. Tide gates are necessary at A or A' to protect interceptor.

Figure 6. Evolution of typical modern sewer system to divert dry flow to treatment.

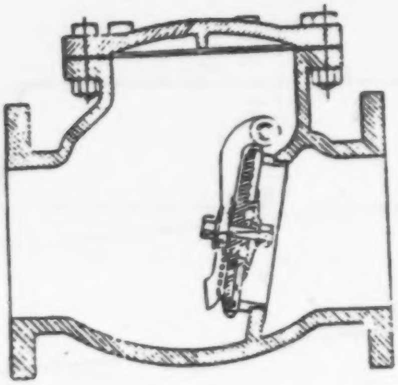


Figure 7. Typical large check valve.

This type, usually of cast iron, is commercially available in sizes up to 2 ft (61 cm) nominal pipe size.

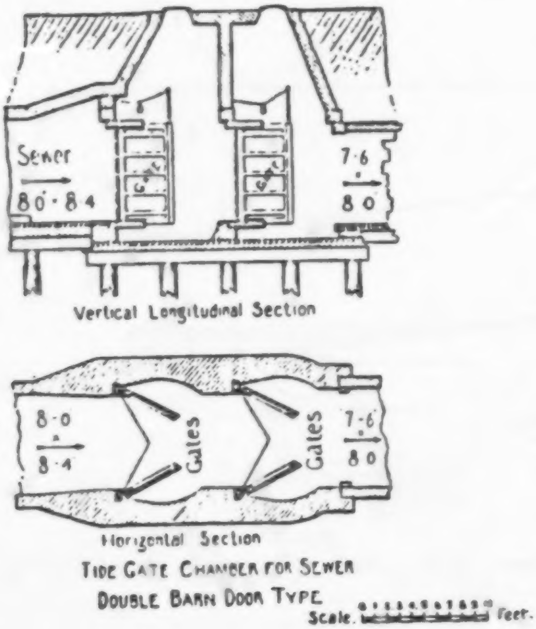

Sewer
8.0 - 8.4
7.6 - 8.0
Gate
Gate
Vertical Longitudinal Section
8.0 - 8.4
Gates
Gates
7.6 - 8.0
Horizontal Section
Tide Gate Chamber for Sewer
Double Barn Door Type
Scale.
Feet.

Figure 8. Side-pivoted tide gate.

Now obsolete, used in Boston about 1900.

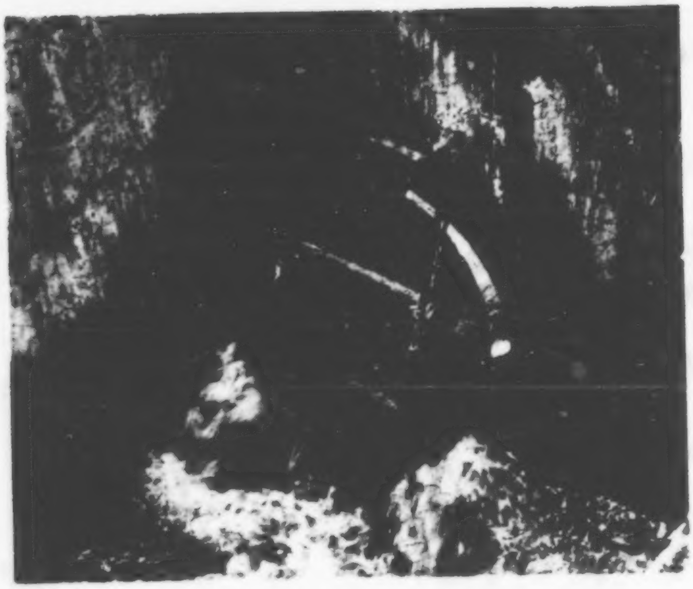
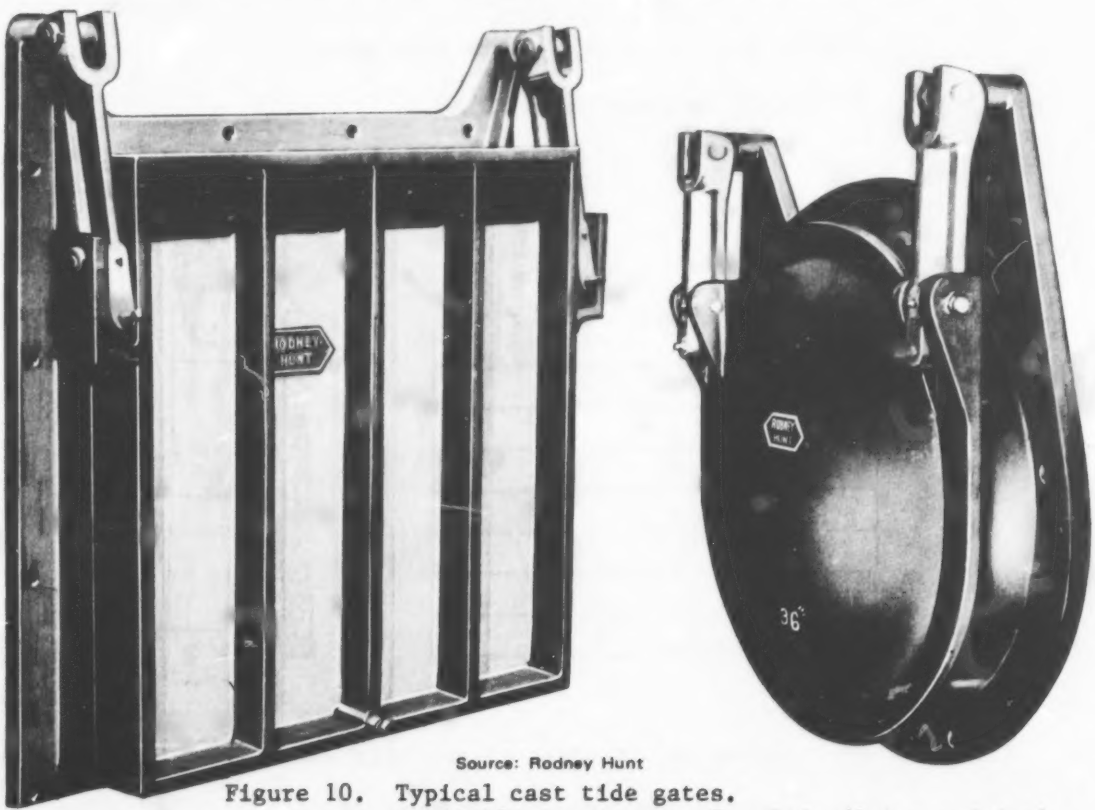


Figure 9. Typical flap gate or flap valve.
Commercially available in sizes up to 2.5 ft (75 cm)


RODNEY-HUNT
RODNEY HUNT
36"

Source: Rodney Hunt

Figure 10. Typical cast tide gates.
Available in sizes to 8 x 8 ft (2.4 m x 2.4 m)

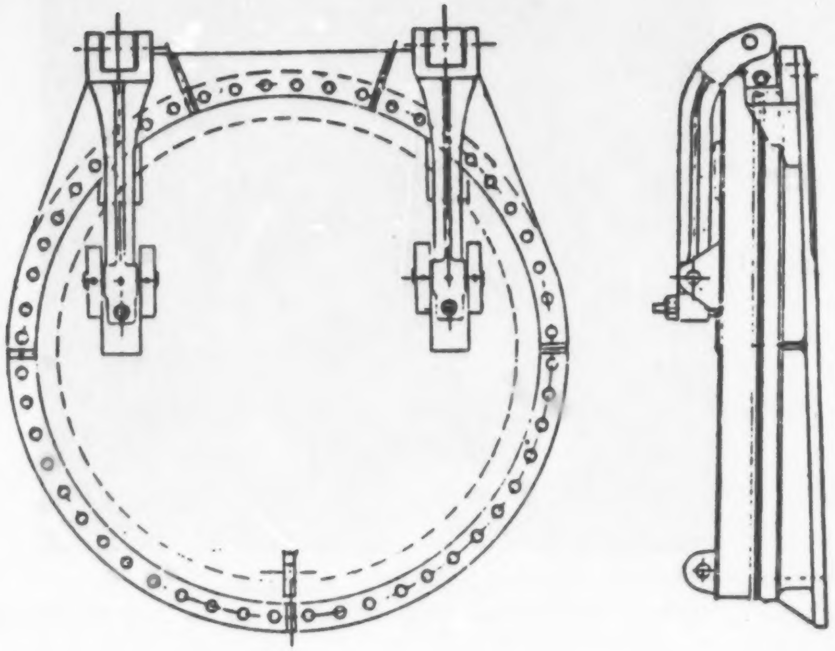


Figure 11. Circular pontoon tide gate.

Available in sizes 10 ft (3 m)

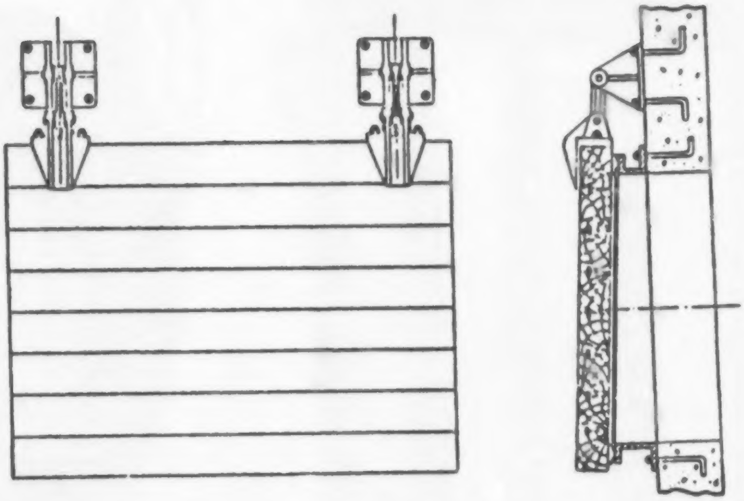


Figure 12. Typical timber tide gate.

Available in sizes over 10 ft (3 m)

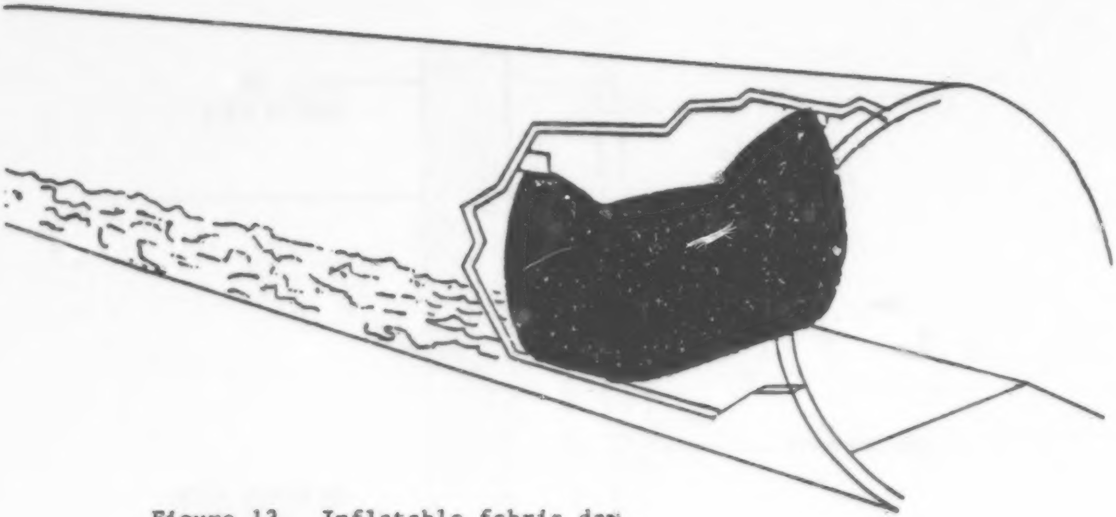


Figure 13. Inflatable fabric dam.

Courtesy: Firestone Coated Fabrics Co.

General Nature of Tide Gate Design

Flap gates are shown schematically in Figure 14. The outlet from the system which is to be protected from backflow terminates in a flat, sloping seat against which the flap hangs. Major rotation is about the upper pivot; the lower pivot provides flexibility to ensure better closure and is standard with larger gates.

The tide gate is actuated by a difference in head across it. The static forces on the flap consist of weight and external head tending to close it, and buoyancy and internal head tending to open it. Friction opposes motion in either direction. Sensitivity of the gate, that is the gravitational force tending to hold it shut, can be adjusted by moving the upper pivot in or out or by adding weights. Design factors are reviewed below and Figure 15 shows the forces which are acting on the gate.

Dynamic forces are usually unimportant, although a sudden, extreme reversal in net head across the flap can cause the flap to pop open and then slam shut. This problem usually occurs on the outlet of large pump systems. Designs are available to reduce the problem. Another area in which dynamic forces can cause a problem is during opening, when in some cases the flap may flutter (12). This situation may occur when flap gates are installed in tandem with discharge to a river. The outer gate may be damaged by wave action after the inner gate seats.

The lower pivot is restricted in its degree of rotation. Too great a rotation about the lower pivot in either direction can cause the upper or lower edge of the flap to hit or enter the seat opening at an angle, causing the gate to wedge open.

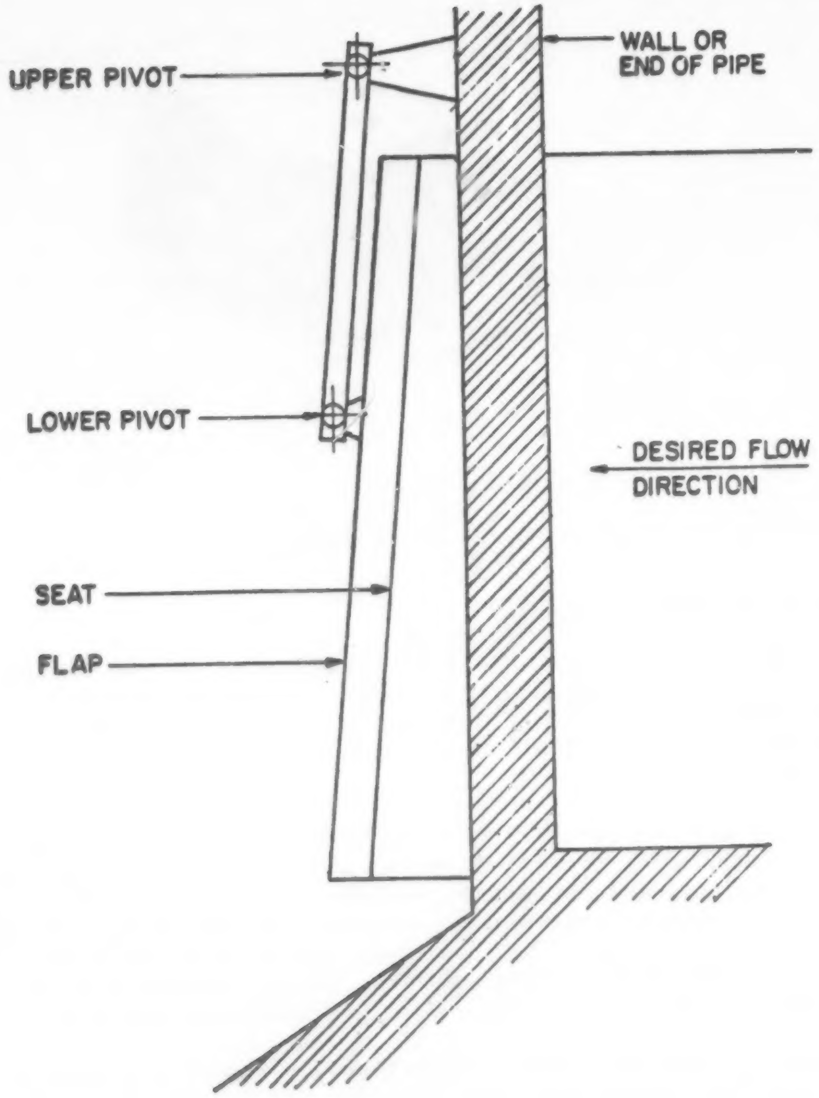

UPPER PIVOT
WALL OR END OF PIPE
LOWER PIVOT
DESIRED FLOW DIRECTION
SEAT
FLAP

Figure 14. Schematic tide gate.

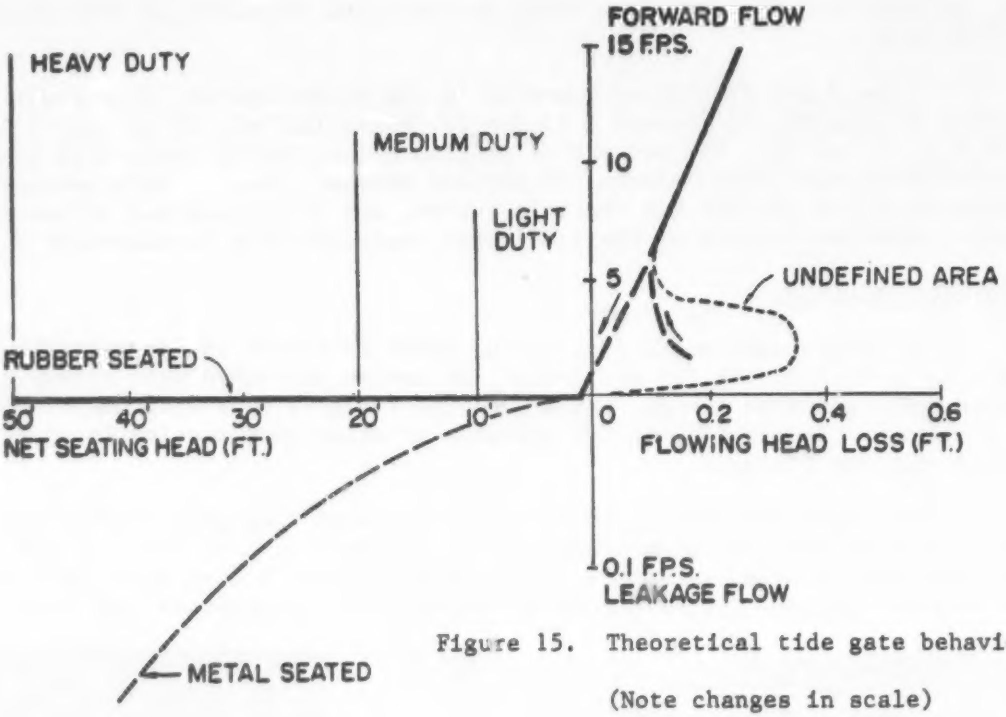


Figure 15. Theoretical tide gate behavior.

(Note changes in scale)

The standard seat is inclined from the vertical to utilize the sealing force of the flap; typically, gates smaller than 18 in. (45 cm) for a 5° slope, intermediate sizes 3° and very large sizes 2°. The flap is designed to withstand the expected seating heads. There is an upper practical size for tide gates because of the strength requirements and difficulties in fabrication. Castings are usually limited to 8 ft (2.4 m) in the major dimension, with pontoon and timber gates, or separate gates being more practical for very large sizes.

Pivots must meet strength and low torque requirements and must also be adjustable in the larger sizes. In most cases, a permanently lubricated design is preferred. Seats can be of base metal, steel, bronze, rubber, etc. They may be installed either on the flap or the frame, or (with bronze) on both. An undamaged soft seat seals best. If damaged, it leaks more than a metal seat.

Timber gates are preferably made from greenheart timber from British Guiana, with suitable metal reinforcement and fittings, and with elastomeric seats, if desired. Tropical woods have become very expensive, therefore gates of southern pine with iron frames and the finished timber creosoted to refusal have been used and are reported to give good service, especially where constantly submerged in polluted water.

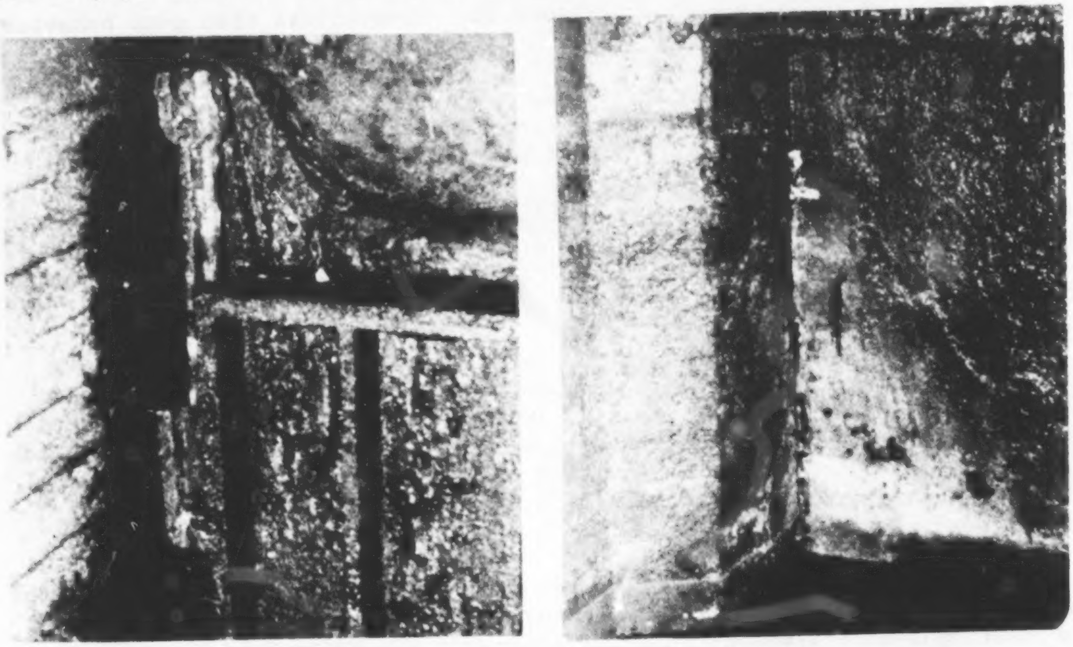
Flexible flap gates can be made in sizes up to 1 ft (30.5 cm). A simple design consists of sections of flat conveyor or power belting, reinforced on both sides by iron discs and hung from the top. This design has successfully replaced cast iron flaps in a silting situation as will be described later.

Of the 1,156 flap gates reported in the recent survey, 26 percent were under 2 ft (61 cm), 31 percent 2 to 3.5 ft (61 to 105 cm), 30 percent 3.5 to 6 ft (105 to 108 cm), one percent of special alloy, and 25 percent of timber. Forty percent had single pivots, 60 percent double. Twenty-three percent had bronze seats, 19 percent had seats of rubber, and 58 percent had no special seats. Nineteen percent of the gates were installed with counterweights.

Tide Gate Selection

The simple cast metal flap valve, shown in Figure 16, is suitable for lines up to 2 or 2.5 ft (61 to 75 cm). It can be furnished with bronze or rubber seats and with flange, collar or pipe (spigot) type attachment. There is usually sufficient play in the assembly to allow good seating in spite of having only one pivot.

The larger circular or rectangular cast iron flap gate usually has doubly-pivoted arms and is the common choice from 1 to 8 ft (30.5 to 240 cm). They are usually provided with a flat back to bolt to a flat wall, wall thimble or pipe flange. The main casting is available in standard cast iron



Courtesy: C. E. Maguire

A. Shows hinge detail of a flap gate

B. Shows the back side of the flap gate. Note debris stuck along closing which does not allow complete closure.

Figure 16. Typical urban tide gate installation.

or alloyed with nickel (Ni-resist), while the seats, faces, links, pivots, etc. are available in a variety of materials. Special modifications are available to restrict openings beyond 90° or to cushion slamming.

Pontoon and timber gates are used where available slopes are very small because their weight is less than cast gates and less head is required to open them or hold them open. They are commonly available in sizes from 3 to 10 ft (90 to 305 cm). Corrosion can destroy a pontoon gate faster than a cast gate, since there is less metal, consequently the base material must be carefully selected. A timber gate must usually be larger than the equivalent cast gate to have equal strength. Timber gates not heavily impregnated are subject to rotting and attack by marine borers in relatively unpolluted water. Those made from greenheart seem to last as long as any other type.

Flexible flap type gates apparently work better and longer than cast flap gates where the water is very dirty or high in solids and there is insufficient flushing action.

Most installations are made with the gate the size of the discharge pipe, or its equivalent. Installing a smaller gate, if sufficient for the flow, would generally be more expensive than to construct a transition section.

Selection Recommendations

The small, single-pivoted flap valve is suitable for most cases up to 2 ft (60 cm). Where leakage must be prevented, neoprene or similar soft seats are available. Principal disadvantages are that the simple hinge pin may bind or freeze, due to corrosion or fouling, and that the rigid flap may fail to seat properly.

Cast flap gates, with doubly-pivoted hinge links, are the most common type. They are available with hardware of almost any desired material (steel, Monel, stainless, bronze, etc) and with metal or resilient seats. They have a certain minimum sensitivity, about 2.5 in. (6.2 cm), that can be decreased by adding weights. In the large sizes, especially in heavy duty construction, they become rather heavy and expensive. In certain instances, they can have too little sensitivity (because of weight) or can flutter or slam.

Timber and pontoon gates are preferred for large facilities but are apt to suffer from corrosion or decay more rapidly than cast gates.

Flexible flap gates are reported to function longer between cleanings than the cast type in heavy silting operations but they are not widely available and their practical service life is yet to be determined.

Receiving Water Considerations

Industrial wastes and saline waters pose special corrosion problems that are best addressed on an individual basis. The largest user of pontoon gates (New York City) is reported to have abandoned this type because of their rapid corrosion, but the material specified for their fabrication (wrought steel plate) was probably inferior. They are in use in Philadelphia and Omaha, to cite two examples. Timber gates of pine are reported to decay fairly rapidly, unless heavily creosoted. The use of tropical greenheart is reportedly quite successful, although there may be a problem with marine worms and the like when the receiving waters are freed of pollution.

Preferred Materials

Cast iron, galvanized steel, bronze and Neoprene rubber and greenheart timber are the most popular materials and are generally suitable. The APWA survey indicated that only seven percent of gate failures were reported as being due to corrosion, and the mean service life is estimated at between 10 and 100 years. Nickel-bearing or Ni-resist cast iron is available, as is type 316 SS where the cost can be justified.

Performance

Users are reported to be 80 to 90 percent satisfied with their existing tide gate facilities. Fouling and sticking cause about 60 percent of malfunctions. Gates are visited an average of 14 times a year at an annual maintenance expense of $194 and 23 man hours per gate. In spite of this, from half to two thirds of all agencies reporting stated that they experienced problems due to malfunctioning tide gates, and that the resulting system overloading occurred about 29 days each year. Such malfunctions may contribute large amounts of inflow, depending upon receiving water levels. Gate life is estimated at 35 years.

Modifications

Tide gates are modified:

1. By substituting materials, in whole or in part, for improved corrosion resistance.
2. For better seating by using double pivots and soft seats.
3. To change sensitivity by moving the upper pivot horizontally upstream or downstream in relation to the seat, or by adding or removing weights, or, as in pontoon and timber gates, by using different methods of construction.
4. To reduce friction by using better pivot lubrication. (The complete removal of the pivot results in the flexible flap type previously mentioned).
5. To limit opening overtravel by providing a flexible stop.
6. To prevent slamming, by furnishing shock-absorbing mechanisms.
7. For telemetering for remote monitoring by applying devices to sense gate position.

Tide gate supporting structures are modified:

1. To provide better access, especially for maintenance.
2. With outer barriers, seal walls, dolphins etc. to protect the tide gate from wave action, floating ice and debris in the receiving waters.
3. With additional supports for tandem or parallel gates for increased capacity or to ensure better sealing against backflow.
4. With provisions for telemetering devices.

Maintenance Requirements

Nearly two thirds of all tide gate failures are due to fouling or sticking. Since the quality of the water occurring at the gate can seldom be improved, continual maintenance is the only answer. Many gates are applied to emergency overflows so that they are not often fouled, but in many cases gates will require cleaning after every actuation if they are to succeed in preventing reverse flow.

Maintenance crews vary from one to five men, and may require special equipment such as mobile cranes to open the large gates and air testing equipment to check for flammable vapor or lack of oxygen before entering a manhole. Fire hoses are one of the most used means of removing deposits from gates.

USE OF REMOTE SENSING SYSTEMS

Open Gate Sensors: Proximity sensors have been used successfully to monitor whether or not the gate is fully shut. This information can be used to check for gate malfunction after high water subsides, whether a gate has been caused to open, or when a gate opens and closes in relation to other events.

Level Sensors: Level switches can detect high water levels on the upstream side to indicate when a tide gate may be open. Conductive type probes must be used very carefully, since many may signal falsely due to condensation or fouling.

Flow Rate Sensors: On-off devices, such as simple paddle switches, can sense reverse flow and are desirable for situations in which the gate is usually submerged. A suitable paddle switch, although inherently simple, requires careful and well thought out construction and installation.

Remote sensing systems are expensive, but can be justified on the basis of reduced maintenance and better system performance. The maintenance of the sensing systems must also be carefully considered.

Other Instrumentation

The use of quantitative flow rate sensors is unlikely to be justifiable for the tide gate installation alone, especially since such a sensor would be impaired by the same conditions that foul the gate. Such sensors would also be costly to purchase and maintain.

Tide gate failure can be detected by a systems approach in which inflow to various parts of a sewerage system is monitored for unusually high values. A measure of influent salinity can also be used in certain cases to detect saline water intrusion if a working salinity measuring system is truly available. In any case, leakage of any one gate in a large system is often impossible to detect.

Recommendations for Design Improvements

The present style flap gate is considered good or at least acceptable by 90 percent of users. The principal problems (fouling and sticking) might conceivably be better handled by changing the surface material or the shape, and closure might be made more positive, but otherwise the design is satisfactory. The mechanically actuated gates used by Metropolitan Seattle offer a positive, controlled facility that prevents backflow.

Recommendations for Application Improvements

A major problem in present tide gate installations is accessibility, as was shown in Figure 16. Many of the installations in heavily built-up metropolitan areas and many older installations are accessible only by manhole. Maintainability of a tide gate located under a city street, especially where the gate is always submerged, is a particular problem. Other considerations include protection of the gate from wave action and debris that floats past the gate, and location of the gate so that there is sufficient clearance and solids do not accumulate and prevent closure. Non-corroding ceiling hooks and stop-log slots (on both sides) should be considered.

Installations on pump discharges must be designed with consideration of the possibility of slamming which has also been reported when gates are installed in tandem. Slamming can be cushioned by soft seats.

Tide gate sizing data is scanty. The usual statement is that gates start to open at about 2.5 in. (6.2 cm) differential, but there is no available data of the effect of submergence on head loss. Studies conducted in Iowa in 1923 seem to offer the only reliable data (12). A sizing procedure would be desirable including the effect of submergence, friction, and flap weight on discharge head loss.

Operating Costs

Non-powered tide gates impose no operating costs other than those for amortization and maintenance. Maintenance costs are generally site specific as time for each gate varies with location conditions and past experience. Some gates may be serviced too often, but the trend seems to be to neglect maintenance until problems arise. There appears to be little coordination with treatment plant operations and tide gate maintenance. In some communities tide gates have actually been abandoned due solely to the tide gate facility maintenance cost. Treatment plant operation costs do not appear to have been a consideration in the decision.

Other Designs

Tide gates were defined in the survey as self-acting and self-contained. More sophisticated and more expensive are flood and stormwater control systems using powered gates or dams. Such systems have been demonstrated at Metropolitan Seattle and Minneapolis-St. Paul(9). Fabric dams (see Figure 13) have been extensively tested in Minneapolis and Cleveland(9). Fabric dams are reported to work well when properly installed and so long as water is not permitted to flow over them while they are inflated. Seattle uses sluice gates.

The performance of powered sluice gates in place of tide gates in centrally-controlled systems is considered to be indistinguishable from sluice gates in common service and offers a positive control.

SUMMARY

"Standard" types of tide gates are available from several well-established manufacturers. Users are 80 to 90 percent satisfied with the present design of tide gates. Fouling and sticking cause about 60 percent of malfunctions. The principal problems are of accessibility and maintenance. Tide gates, by their simplicity, have received little attention over the years in spite of their successful utilization in many of the larger municipal systems. When properly applied, however, they can be relied upon to operate successfully for their typical life of several decades with adequate maintenance.

Methods for selection and sizing are very incomplete. For example, data could not be found to indicate opening heads as a function of submergence or friction, or flowing head loss as a function of flap weight. Design manuals for tide gates and sluice gates would be helpful. Manuals of practice or design recommendations for area-wide sensing and control systems would also be desirable. Such manuals should discuss such areas as theory and present practice, recommend standards, and demonstrate practical examples.

Tide gates should be integrated into area-wide control systems. Such integration has been accumulated by only a few authorities, but is within the existing technology. Remotely-actuated gate systems, to supplant tide gates, have also demonstrated their feasibility. They represent a corresponding increase in technology and cost. The positive control which such systems represent offers major advantages and protection to wastewater treatment facilities.

Field visits were made to six authorities. Highlights of the investigator's reports follow.

Akron, Ohio

The sewerage system of Akron consists of combined and separate systems with sewer sizes ranging from 8 in. (20 cm) to 101 x 56 in. (2.6 x 1.4 cm) conduits. One treatment plant serves the area. The plant overflows are not equipped with backwater gates. The system also includes 20 pumping stations, 18 of which have emergency overflows. No mechanical regulators are installed in the 38 combined sewer overflows; control is provided by set weirs or dams.

The system has backwater gates at only five of the 18 pumping stations with overflows. These gates are all flap type and prevent intrusion of local streams into the system. All the gates are cast iron, four under 2 ft (61 cm) and one between 2 and 3.5 ft (61 and 105 cm). First installation was made in 1939 and the latest in 1973. The useful life was estimated at over 25 years and performance was reported as satisfactory despite occasional fouling or sticking. Maintenance is performed on the flap gates only when excessive inflow is observed at the pumping stations.

Akron uses many small, flexible flap gates made from flexible belting of 1 ft (30.5 cm) size, to seal off street catch basins from combined sewers. These gates are more successful than the original cast iron gates that had a tendency to silt up rapidly.

Akron's telemetering system does not monitor backwater gate condition, but only the level at overflows and pumping station operations. Gate malfunctions can be deduced from excessive pumping and wetwell elevations. The telemeter system uses leased telephone lines to transmit signals to a central control station.

Detroit, Michigan

Detroit's wastewater collection system consists almost entirely of combined sewers. Until 1930 the city collector sewers led directly into the Detroit and Rouge Rivers. Then a primary wastewater treatment plant was built and sewers were built to intercept the collector sewers near the outfalls. Automatic regulator stations with outfall tide gates were constructed at connecting points between the interceptor and collector sewers. The backwater gates protect the regulators and prevent high river levels from surcharging the system and overloading the treatment plant through the interceptors. Forty eight of the 76 river outfalls are protected by backwater gates using 108 gates, more than half of which are installed in tandem.

Most of the backwater gates were installed in the 1930s and are still operating. All timber gates were constructed with vertical rather than horizontal members. This design seems to be more economical and provide better hinge connections at the top of the gate. Of the 108 tide gates in the Detroit system, 30-35 are cast iron, the rest timber. Most of the metal gates use brass seals. Some use neoprene.

The Detroit system utilizes proximity sensors on tide gates. The sensors indicate at a central control office whether or not the gate is closed. Other monitoring components consist of rain gauges, inflatable dams and level sensors, etc. all of which are connected to the telemetry system. Most problems with this monitoring system stem from damage to overhead telephone lines during storms.

Maintenance and inspection was performed every 1 or 2 months until recently when trips were reduced to emergency situations only. Problems are encountered after every rainfall large enough to cause gates to open. Debris often prevents complete gate closure, indicating an open gate at the central office.

Included in Detroit's collection system are three inflatable dams, designed to increase storage capacity within the system. The dams are also monitored by central control for inflation pressures and sewage depths retained by the dams.

New York, New York

New York City's sewer system consists primarily of combined sewers and due to the low-lying area and wide tidal changes the system requires extensive protection from flooding. The first tide gates were installed in 1937 when the Wards Island treatment plant was built. As a new treatment plant was constructed, tide gates were also installed at interceptors to protect the system.

The New York system has approximately 365 tide gates. The various gates include 160 flap type, 100 pontoon and 105 timber gates. Flap gates range from under 2 ft (61 cm) to 6 ft (1.8 m), pontoon type are used for 3.5 to 6 ft (1.05 to 1.8 m) gates, and timber gates are used for larger applications. A limited number of tide gates were reported to be installed in tandem or in parallel with two or more units protecting the same regulator chamber. Tide gates are located on the downstream side of regulator chambers and approximately 10 gates are used between sanitary sewers and combined or storm sewer interconnections. The latest tide gate was installed in 1974. No pontoon gates have been installed since 1960. In the future, New York plans a new treatment plant and interceptors with tide gate protection.

The City's experience with tide gates shows that cast iron gates have a long useful life, with a few cases of broken hinges and casting. The cast iron gates have resisted corrosion, unlike the steel pontoon gates that have rusted and deteriorated after 10 years. Because of the short useful life and their lack of rigidity, the City no longer specifies pontoon gates. Most of the pontoon gates in service are in poor condition. Original timber gates had a reported life of approximately 10 years, but timber gates are now built with vertical planks of tropic hardwood. This new design is expected to extend the useful life. New York uses resilient seals on all their gates. Most of their gates are usually partly or wholly submerged.

The performance of the iron flap and new timber gates was reported good, but poor for the old yellow pine gates. Typical gate failures for all three type gates included sticking or binding, fouling, corrosion and broken hinges or frames. Tide gates and regulators are maintained by five crews consisting of five men in each crew. Servicing and inspection varies from once a month to once a week. Servicing trips are on a routine schedule, with additional trips as required to answer complaints. The estimated man-hours per year was 16,000 for 1974 and $100,000 per year for cost of maintenance. The above estimated values yield 43 mhr/yr/gate and $274/yr/gate.

Excessive flows observed at pumping stations, treatment plants or interceptors are used to alert crews to possible tide gate malfunctions. The system is under daily surveillance for salt water inflow. High salt concentrations alert crews for additional check-ups.

Metropolitan Seattle, Washington

The Metropolitan Seattle area sewerage system comprises 20 pumping stations, 16 regulators and 5 wastewater treatment plants. The service area is generally served by combined sewers. The 16 regulator stations are typically constructed at intersections of collecting sewers and interceptors. Each station consists of a chamber with a regulator gate to modulate wet weather flow into the interceptor and an overflow/outfall protected by a power actuated sluice gate. Monitoring allows operation of the sluice gate only when there is sufficient upstream head to allow discharge.

Numerous sensing devices are used in the Seattle system. Level sensors in interceptors, regulator stations and outfalls control the sluice gates and prevent ocean water from entering the system. The entire sewerage system is monitored and controlled through a central computer station and two satellite stations located at the major treatment plants.

The Seattle systems use only four conventional tide gates, one is over 6 ft (183 cm) and protects a lift station and three are between 2 and 3.5 ft (61 and 105 cm) and provide emergency high level relief at regulators. All gates are top hinged and cast iron with monel seats. No monitoring system is used on these tide gates and no information was available relative to performance or maintenance other than all systems are checked quarterly. No dissatisfaction was expressed with operation of the four flap gates.

Minneapolis-St. Paul, Minnesota

During the 1950s and 1960s studies of the Minneapolis-St. Paul sewerage system revealed that combined sewer overflows occurred even at times when interceptor sewers were operating at less than capacity. In 1966 a program was initiated to modify the regulators and construct a central computer monitoring and control station. Sixteen control and monitoring stations were constructed to handle 80 percent of the system's combined sewage. Inflatable dams were installed immediately downstream from the mechanical regulator gates, which are operated by hydraulic cylinders. Gate position is sensed by mechanical potentiometers for telemetry.

The central computer station monitors sewage elevations in interceptor and trunk sewers, positions of regulator gates, air pressure in the inflatable dams, levels in rain gauges and river quality from sample stations. The computer, however, does not operate the system.

Although the Minneapolis-St. Paul system has extensive overflow facilities, at present it does not utilize conventional type tide gates.

SECTION VII

RECENT RESEARCH AND DEVELOPMENT ACTIVITIES

Relatively limited research work has been carried out on methods or practices aimed at reducing infiltration, other than product development work by pipe manufacturers. This study has identified five recent or ongoing research and development actions which merit consideration. The following discussion is intended to indicate the nature of these specific fields of research and development as examples of the types of studies which are needed to improve I/I conditions in sewer systems.

PIPES AND JOINTS

Heat Shrinkable Joints

The usual location of entry of infiltration into otherwise structurally sound sewer systems is at line joints, at the connection of the house lateral to the collector sewer and at manholes. Some pipe systems have minimized the number of joints by using long pipe sections where the weight of the pipe is not so great as to impede handling ability.

Other pipe systems have used chemical welds to produce tight joints.

Heat shrinkable plastic tubing (HST) has been developed and researched by the Western Company (13). Laboratory studies of materials and joints were conducted to determine their characteristics and their operational and economic feasibility. A wide variety of HST materials and joints were tested in addition to conventional joints for clay, concrete and asbestos-cement pipe.

The results of both small-scale tests and full-scale tests using commercial 8 in. (20 cm) sewer pipe indicated that a polyolefin with a polymeric base hot-melt adhesive produced the most durable, watertight joints and were significantly superior in performance compared to existing pipe joining methods. In addition, cost analyses indicated that HST joints are economically feasible and compare favorably to conventional joints when considering both material and installation costs. The HST joint does not require a bell or other enlarged pipe end. Thus, the breakage of the pipe in shipping and job site handling is reduced, cost of production is lowered, and bridging between joints in the trench and structural failures are minimized.

The use of HST joint has been accepted by manufacturers and can be purchased from many suppliers. For example, the joint system has been used with smaller diameter clay pipe.

Impregnation of Concrete Pipe

The use of concrete pipe for sanitary and combined sewers has been affected in many areas because of concern over corrosion of the concrete. Concrete pipe is produced widely over the nation and has been used extensively for many other systems, notably separate storm sewers.

The Southwest Research Institute conducted a study (14) concerning the impregnation of concrete pipe. The study sought to provide a method to increase corrosion resistance and strength, and reduce the permeability of concrete used in sewer line applications by impregnating the pipe with low-cost resins.

Figure 17 shows the area where sewer pipe is usually attacked.

The use of sulfur or five percent hydrofluoric acid resulted in a decrease of 10 to 30 times the rate of corrosion loss. The cost of such treatment was estimated to be from $0.05 to $0.15/ft^2 ($0.54 to $1.61/m^2) depending upon the material used. The cost of plastic lining, on the other hand varies from $0.85 to $1.00/ft^2 ($9.15 to $10.76/m^2).

The study concluded that there is a possibility that lines could be treated in place.

SEWER CONSTRUCTION

Trenchless Sewer

Plastic pipe, because of its light weight and flexibility, has been used in relatively long lengths in Europe for some time. Some projects have extended the pipe length at the job site to permit extremely long pipe sections between chemical welds. However, these applications have generally been used for water lines.

An adaptation of European practice to sewer construction is being demonstrated in Sussex County, Delaware, by the Evanston Development Corporation (15), where 1,500 ft (457 m) of sewer line has been "plowed in."

A contract for installation of the test sewer was awarded, in September 1974, to the Evanston Development Corporation, Huntington Valley, Pennsylvania.

The trenchless pipe laying system was developed in England in the early 1960s. It has been employed throughout Europe to "plow in" pipe, cable and conduit. The equipment simultaneously forms a tunnel and installs a pipe in a continuous and rapid manner.

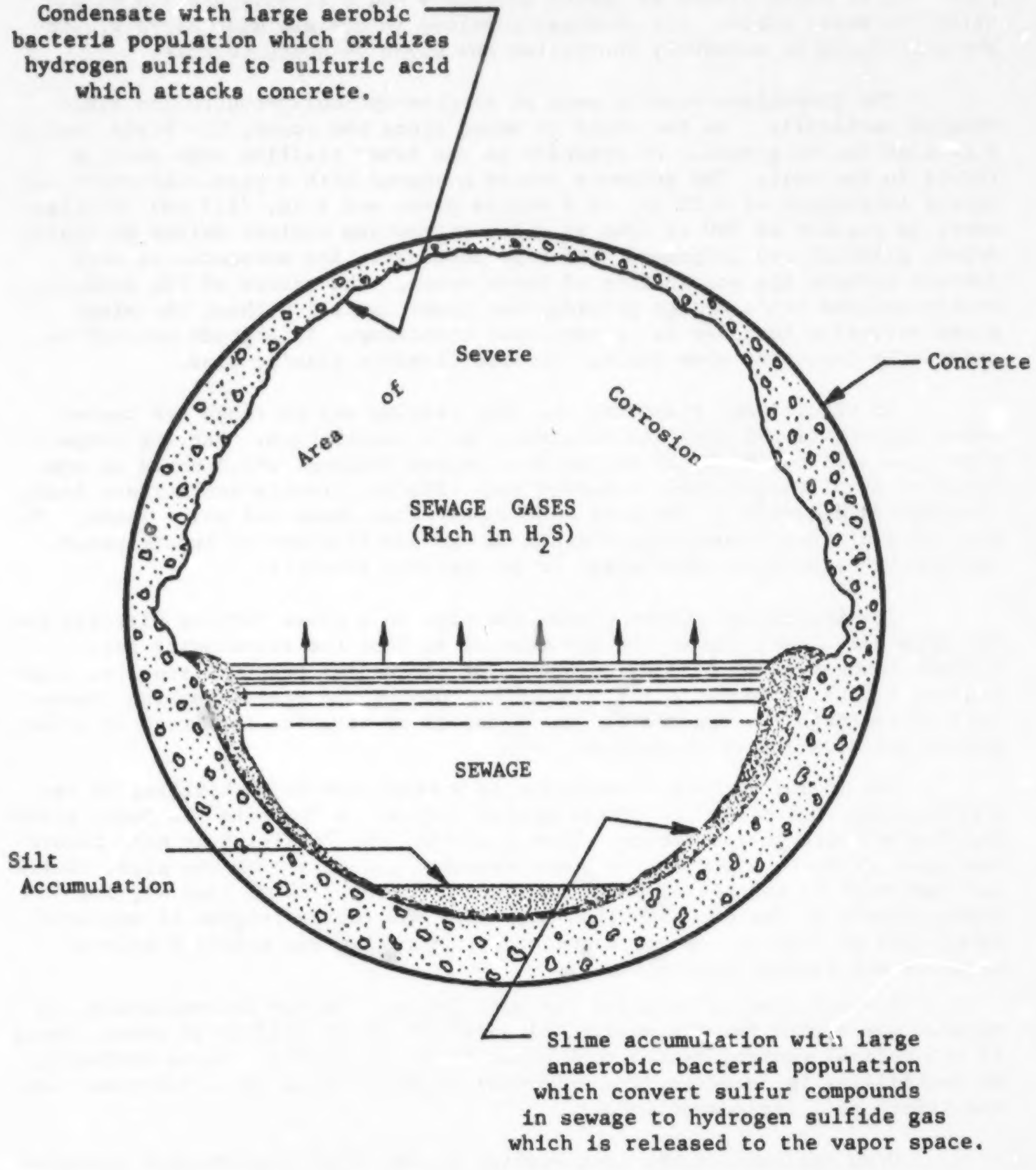

Condensate with large aerobic bacteria population which oxidizes hydrogen sulfide to sulfuric acid which attacks concrete.
Area of Severe Corrosion
Concrete
SEWAGE GASES
(Rich in H_2S)
SEWAGE
Silt Accumulation
Slime accumulation with large anaerobic bacteria population which convert sulfur compounds in sewage to hydrogen sulfide gas which is released to the vapor space.

Figure 17. Cross section of concrete sewer pipe under typical corrosion conditions.

The sewer being installed is 8 in. (20 cm) diam. schedule 40 PVC pipe. It is being placed at depths between 4 and 6 ft (1.2 and 1.8 m) and below the water table. All chemically welded joints are made above ground where they can be carefully controlled and given 24 hours to cure.

The trenchless machine uses an electro-optically-controlled blade mounted vertically. As the blade is moved along the route, the blade forces a passage in the ground. An expander on the lower trailing edge opens a tunnel in the soil. The guidance system operates with a precision which satisfies tolerances of 0.25 in. (0.6 cm) in grade and 1 in. (2.5 cm) in alignment, in reaches of 800 ft (244 m). The automation control method maintains depth, gradient and alignment with high accuracy. The automatic control feature reduces the possibility of human error. The nature of the guidance system and the blade design provides for grade control without the minor grade variation involved in conventional trenching. This grade control is especially important when laying the more flexible plastic pipe.

In traditional trenching the pipe bedding may be rough and uneven requiring additional work and materials for stabilization. Varying compaction levels in the backfill may produce uneven loadings which could be complicated by slippage loads, reversed arch effects, gravity and surface loads transmitted directly to the pipe and concentrated shear and point loads. The most careful trench bedding practices may be insufficient to insure proper bedding in high water table areas or in unstable subsoils.

The trenchless system places the pipe in a close fitting circular bed. The expander closes the top of the channel so that the surrounding soil becomes homogeneous. Even distribution of the radial pressure results, eliminating excessive loads in any direction. During the operation, the tunnel wall is thoroughly compacted and the prospect of abrasion from rock or stone during installation is minimized.

The ground surface disturbance is minimal and no backfilling is required beyond restoring the single access trench. A "pull-in" is made, starting from a short access trench. When possible, the "pull-in" is made toward shallower grade to minimize the power required and strain on the pipe. While the equipment is capable of handling lengths up to 1,200 ft (366 m), the piping layout at the demonstration site used continuous lengths of approximately 800 ft (244 m). Thus, conventional trenching was required only at manholes and lateral connections.

A short time is required for pipe laying. In one demonstration, 10 minutes was needed for the entire "plow-in" of 400 ft (122 m) of sewer. Setup of the optical control system took about 15 to 25 minutes. Since virtually no backfilling is required, the only time required is to run a bulldozer over the trench path for compaction.

Upon approval of the test section by the Chief Construction Inspector, an additional 4.7 mi (7.6 km) of sewer will be put in place using the trenchless technique.

It is claimed that the trenchless system should:

1. Reduce construction costs by an estimated 29 percent when compared to conventional methods of construction.
2. Provide a system which includes better grade maintenance, make-up of pipe joints above ground and curing for 24 hours before being disturbed, better joints.
3. Reduce construction time, minimizing interference with the residents and traffic flow.
4. Reduce areas of disturbance and costs of reconstruction and paving.
5. Lower workers' exposure to hazards of trench construction.
6. Allow a longer construction season, especially in areas where disruption cannot be tolerated.

Among the major limitations on the use of trenchless installations is the size of the pipe which can be handled, and the need to be first in construction, because other utilities must be placed after sewer installation.

SEWER BEDDING

The Gulf Coast area has many places with high water tables and deltas or alluvial soils. Infiltration of sewer lines has presented particular problems in such areas.

Tulane University (16) conducted a study of sewer bedding practices for the region. Infiltration studies were conducted in 1962, 1963 and 1970. The results, when compared, varied from slight increase to decreases in infiltration. The decreases were attributed to soil and grease clogging the points of entry. Three and one-half percent of the manholes were found to be experiencing infiltration at the time of inspection.

It was concluded that poor construction techniques were the major cause of the infiltration problem. Bedding material has been generally used only for providing uniform support for the pipe and distributing the load over the entire length of the pipe in order to reduce the possibility of structural failures. The Tulane report suggested that an additional function should be to impede the flow of groundwater along the pipe trench.

The report recommended that in high groundwater areas where graded materials are used for bedding, bentonite or other expanding materials, or sand and Portland cement be mixed with the bedding material.

Major observations were made on the extent of line settlement. Field findings could not be duplicated in the laboratory, emphasizing the need for well-controlled field construction practices. A major problem in sewer lines was found at points of infiltration where grease introduced from kitchen food-waste grinders tended to coagulate upon contact with the cooler groundwater.

The importance of flexible joints for use in areas with poor bedding characteristics was also shown. A moulded joint sewer pipe was tested under a head of 30 ft (9.1 m) of water and a deflection angle of 10.9 degrees before leakage was observed.

SEALING

Evaluation of Sealing

The Montgomery County Sanitary Department, Dayton, Ohio, conducted a sealing program for small-diameter lines beginning in 1957. In 1968, a program was initiated to investigate the effects of infiltration reduction by joint sealing and to study closed-circuit TV techniques(17). The report documented the difficulties in performing an evaluation, the techniques used, and the limited usefulness of the conclusions. Information concerning cost, equipment, procedures and organization was given in detail.

For the County system it was concluded that inflow was the major source of extraneous flow, so much so that the effect of joint sealing was obscured.

The use of a flow-through packer design was found useful in eliminating the pumping of sewage around the section being sealed.

Rapid rises in the groundwater table were observed after sufficient precipitation had saturated the soil. Therefore, the flow from pipe line leaks may be much higher during periods of precipitation than noted during the time of inspections.

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